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# Scientific Names of Latin and Greek Derivation.

BY

WALTER MILLER,

*Professor of Classical Philology, Leland Stanford Jr. University.*

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# PREFATORY NOTE.

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CHARLES H. GILBERT,
OLIVER P. JENKINS,
VERNON L. KELLOGG,
*Directors Hopkins Laboratory.*

Date of publication, April 10, 1897.

# SCIENTIFIC NAMES OF LATIN AND GREEK DERIVATION.

BY WALTER MILLER,

*Professor of Classical Philology, Leland Stanford Jr. University.*

While the first volume of Jordan and Evermann's "Fishes of North and Middle America" was in preparation, Dr. Jordan invited me to review and verify the etymologies of the names of the fishes described. In the course of this review some of the inconsistencies into which nomenclators have fallen in the construction of names of classical derivation came frequently under discussion. Two sets of words seemed to cause more trouble than any others: what should be the gender and inflection of compounds in -pus (genitive, -podis) and -stoma, -soma, etc. (genitive, -stomatis, -somatis, etc.), and what the form of the family names to be derived from them, were the questions that called for an immediate answer. As thorough an investigation as possible followed and a satisfactory conclusion was reached. But the examination of the problems these questions presented naturally suggested others in regard to the formation, gender and inflection of New Latin compound names; for most of the irregularities in scientific nomenclature are of that sort. Here and there we find masculine nouns in -a (genitive, -ae) masquerading as feminine, feminine nouns in -us (genitive, -i) and neuters in -us (genitive, -us, Greek -ους) as masculine, and neuters in -ma (genitive, -matis, Greek -ματος) as feminines in -*a* (genitive, -ae). Again, through a misconception of the inflection of a word it often appears in compounds and in family names in a sadly mutilated form.

Various scientific writers have arbitrarily departed from the philologically correct method of nomenclature established by Linnæus;[1] moreover some difference of opinion now prevails in regard to the formation, gender and inflection of certain New Latin words derived from the Greek. Definite rules have been wanting, or at least not readily available. Accordingly, at Dr. Jordan's request, and with his kind assistance, I have undertaken to formulate a set of rules based upon philological principles and at the same time agreeing with the practice of consistent nomenclators. Ultra-purism, however, as the writing of ai and oi for the Greek αι and οι or of k for Greek κ, shall have no more consideration than the philological monstrosities produced by a Rafinesque or a Swainson.

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[1] Even Linnæus, however, is not absolutely free from errors in transliteration: e. g. *Systema Naturæ*, I$^{12}$: Oxy-rinchus (pp. 395 and 512), Callorynchus (p. 402), Gono-rynchus (p. 528), Di-delphis (p. 71), Syngnathus, as masculine (p. 416).

1 There is no essential difference in the method of procedure whether we are adopting from the classical languages simple words or compound words; but as not all the desired compounds exist ready made for us in Greek and Latin, and as their formation causes more trouble, the compounds will be assumed as the subject of these rules.

2 Compounds in scientific terminology, whether Latin or Greek, are usually made up of two parts, which would naturally be separate words standing in some syntactical relation to each other and which combine that relation in one word; either member may be a form that is not a word by itself but appears only in compounds: e. g. Eng. *un*-told; *un-* appears only as inseparable prefix; in up-*ward* *-ward* appears only as inseparable suffix. So Latin *ve*-sanus (inseparable prefix *ve-* +sanus) out of one's senses; fun-*ambulus*, rope-walker; Greek δυσ-άλωτος, *hard to be caught*; πολυ-πράγμων (πολύ, *much*, + πράττω, *do*), meddlesome.

3 Besides these two elements, a third is in every case to be taken into consideration—the inflectional ending, which determines the sentence relation of the word; this inflectional ending may or may not be identical with that of the last member of the compound: e. g. in λευκ-όφθαλμος (λευκός, *white*, + ὀφθαλμός, *eye*), *white-eyed*, and in Πελοπόν-νησος (Πέλοπος, *Pelops'*, +νῆσος, *island*), Peloponnesus, it is; but it is not so in μακρο-κέφαλος, *long-headed*, derived from μακρός, *long*, + κεφαλή, *head*, nor in μακρ-οῦρος, *long-tailed*, derived from μακρός, *long*, +οὐρά, *tail*; but in passing into

a compound adjective the stem *κεφαλα-* of *κεφαλή* and the stem *οὐρα-* became, after the irresistible analogy of the *o*-stems, *κεφαλο-* and *οὐρο-*, and to those stems the masculine nominative case-ending -ς was added. Such changes will be more apparent as we proceed.

## HYBRID WORDS.

4 In building a compound name the two classical languages should never be mixed. The new word should be wholly Greek or wholly Latin. Hybrid words are always objectionable, and such compounds as Swainson's Felichthys, as Longicephalus, Leptogunnellus, Flavigasster, Gymnocorvus, Arboro-phila and the like, are enough to make one's hair stand on end.

## LATIN COMPOUNDS.

Latin is, comparatively speaking, poor in compound words. In place of doubling up words, significant suffixes are added, or the words, retaining their proper syntactical relations, are simply written together as one: e. g. pater-familias, iuris-dictio, etc. Still, the language contains many genuine compounds of every part of speech—substantives, verbs and adverbs.

5 In entering into composition as first member of a compound, a noun or adjective appears not in its familiar, nominative singular form, but as its stem or a modification of its
6 stem.[1] If the stem ends in a vowel and the second member
begins with a vowel, the vowel of the first is elided: e. g.
somn-ambulus (somnus, stem somno- + -ambulus),

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[1] But less than the stem must not be used in any case; no change in a word may be made except in the variable terminations. "A name made up of the first half of one word and the last half of another is as deformed a monster in nomenclature as a mermaid or a centaur would be in zoölogy." A worse linguistic monstrosity than Cor-corax (from Corvus and *Πυρρο-κόραξ*), both hybrid and mutilated at that, it would be difficult to conceive; and yet it stands. Other examples of the same violation of law we have in Cypsnagra (*κύψελος* + *Τανάγρα*), Merulaxis (Merula + *Συνάλλαξις*), Bucorvus (*Βουκέρως* + Corvus), etc.

magn-animus (magnus, stem magno- + animus).[1]
7 But if the second member of the compound begins with a consonant, the final vowel of the first member will appear as i. For even in the case of *a*, *o*-[2] and *u*-[3] stems the final vowel is, in accordance with well known phonetic laws, naturally weakened to -*i*- [man-ceps, *contractor*, and mancipium, *contract* (derived from manus, *hand* + capere, *take*) have lost even the -*i*-]: e. g.

tub-i-cen (tuba, *horn*, + can-ere, *sing*), *horn-player;*
curv-i-rostris (curvus, stem curvo-, *curved*, + rostrum, *beak*), *having a curved beak;*
spin-i-barbus (spina, *spine*, + barba, *beard*), *having a beard of spines;*
hort-i-cola (hortus, stem horto-, *garden*, + colere, *dwell*), *dwelling in a garden;*
navi-ger (navis, stem navi-, *ship*, + ger-ere, *bear*), *ship-bearing;*
corn-i-ger (cornu, stem cornu-, *horn*, + ger-ere, *bear*), *horn-bearing.*

8 In the case of stems in -*io*-, the *o* simply falls out and leaves the first member ending in -*i*-, as in the other cases: e. g.

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[1] Forms like multi-angulus (side by side with mult-angulus) are of later manufacture and the result of analogy with forms where no hiatus occurs.

[2] Where -o- appears in the junction of compounds, it is due to the influence of the Greek compounds: e. g. albo-galerus, *the flamen's hat;* uno-mammius, *single-breasted.* Accordingly, such formations as albo-caudatus, *white-tailed*, as participial form to albi-cauda (adjective), or rubro-punctatus, *red-spotted*, or rubro-vinctus, might be perfectly legitimate in epic poetry but not in Latin prose nor in strictly correct New Latin construction.

[3] A -u- seems sometimes to remain unchanged: e. g. nau-fragus (navis, stem navi-, + √frag, frangere, *to break)*, *ship-wrecking*, for navi-fragus, arose in the same way as Greek *ναυ-αγός*, and in the same way bu-caeda (cf. bovi-caedium) and bu-mammus were made after the analogy of the Greek compounds of *βοῦς*; manu-mitto, manu-factus, etc. are not due to composition, properly speaking, at all, but to juxtaposition, manu- being not the stem but the ablative case.

medi-terraneus (medius, stem medio-, *middle*, + terra, *land*), *between lands;*
heredi-peta (heredium, *legacy*, + pet-ere, *hunt*), *legacy-hunter;*
offici-perda (officium, *office*, perd-ere, *lose*), *labor-losing.*

9 The same analogy has forced itself through in the case of consonant stems as well, so that a connecting vowel *-i-* is inserted between the consonant stem and the second member:[1] e. g.

part-i-ceps (pars, stem part-, *part*, + cap-ere, *take*), *sharing;*
dent-i-frangibulus (dens, stem dent-, *tooth*, + frang-ere, *break*), *tooth-breaking;*
soror-i-cida (soror, stem soror-, *sister*, + caed-ere, *kill*), *sister-slayer;*
fratr-i-cida (frater, stem fratr-, *brother*, + caed-ere, *kill*), *brother-slayer.*

The treatment of the first member is the same for both nouns and adjectives.

10 The final member of a Latin *substantivum compositum* may be a substantive (noun, adjective, participle) or a verb, and the whole will appear, according to the will of the coiner, as noun or adjective; its form will be decided by

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[1] Rarely, instead of adding *-i-*, the consonant stem loses its consonant: e. g. iu-dex, (ius, stem iur-, *law*, + dic-ere, *speak*); but it seemed unnatural and so a iur-i-dic-us was made according to rule, with the same meaning; in the same way lapi-cida (lapis, stem lapid-, *stone*, + caed-ere, *cut*) was also followed in due time by the normal lapid-i-cida, *stone-cutter.*

The forms with the connecting vowel *-i-* are by far the most numerous; they are the only ones that we may take as our models, for, analogous forms though they are, they represent the only method of formation in use in classical times. The older method, of which only a few specimens are left, was simply to prefix the stem of the first member to the second and leave the consonant to take care of itself: e. g.

sol-stitium (sol), *solstice;*
mus-cipula (mus), *mouse-trap;*
nomen-clator (nomen), *name-caller.*

the form of the final member. If the whole is to be a NOUN, its form will be governed by the following rules:

11 1. If the final member of a Latin *nomen compositum* is a noun, the compound noun will have the form and gender and inflection of that noun: e. g.

pro-avus, -i, masc. (avus), *great-grandfather;*
decem-vir, -i, masc. (vir), *decemvir;*
de-decus, -oris, neut. (decus), *disgrace;*
meri-dies, -ei, fem. (dies), *midday;*
bi-dens, -dentis, masc. (dens), *fork.*

12 2. If the final member of a Latin *nomen compositum* is a verbal root, the compound noun will be (*a*) a masculine
13 noun of the first declension ending in *-a*, (*b*) a noun of the third declension: e. g.

(*a*) agri-col-a, -ae (ager, *field*, + col-ere, *till*), *farmer;*
fratri-cid-a, -ae (frater, *brother*, + caed-ere, *slay*), *fratricide;*
lapi-cid-a, -ae (lapis, *stone*, + caed-ere, *cut*), *stone-cutter;*
(*b*) tibi-cen, -cinis (tibia, *flute*, + can-ere, *sing*), *flute-player;*
man-ceps, -cipis (manus, *hand*, + capere *take*), *contractor;*
iu-dex, -dicis (ius, *right*, + dic-ere, *speak*), *judge.*

14 In forming compound ADJECTIVES, the final member, as well as the first, is strongly influenced by the analogy of the *i-* stems, so that we have compounds with stems in *-o-* and *-a-* (nominative singular in *-us* and *-er*, masc., *-a*, fem., *-um*, neut.), with stems in *-i-* (nominative singular in *-is*, masc. and fem., *-e*, neut.), and with stems ending in a consonant (nominative singular in *-s*, preceded by a consonant, or in *-r*), according to the following rules:

15 1. If the final member is a noun (*a*) of the first declension,
with stem ending in *-a-*, or (*b*) of the second declension,
with stem ending in *-o-*, or (*c*) of the fourth declension,
with stem ending in *-u-*, the compound adjective (A) may
16 have the endings *-us*, masc., *-a*, fem., *-um*, neut., or (B)
after the analogy of the *-i-* stems, it may appear with the
endings *-is*, masc. and fem., *-e*, neut.; as there is nothing
by which to decide, we often find both: e. g.

| (A) | (B) |
|---|---|
| (*a*) im-berb-us (im-, *not*,+barba, *beard*), *beardless*, | (*a*) im-berb-is; |
| in-fam-us (in-, *not*,+fama, *fame*), *infamous*, | in-fam-is; |
| in-anim-us (in-, *not*,+anima, *life*), *lifeless*, | in-anim-is; |
| se-cur-us (se-, *without*,+cura, *care*), *careless*, | |
| (*b*) in-anim-us (in-, *not*,+animus, *life*), *lifeless*, | (*b*) in-anim-is; |
| multi-iug-us (iugum *of many yokes*), *manifold*, | multi-iug-is; |
| in-erm-us (pl. arma, *arms*), *unarmed*, | in-erm-is; |
| multi-cav-us (cavus, *cave*), *of many caves*, and | ex-somn-is; |
| (*c*) quadri-man-us (manus, stem manu-, *hand*), *four-handed* | (*c*) quadri-man-is; |

multi-fruct-us (fructus, *fruit*), *abounding in fruit*, but bi-corn-is, (bi-*two*,+cornu, *horn*), *two-horned;* so angui-corn-is, *serpent-horned;* etc.

17 2. If the final member is a noun of the fifth declension, with stem ending in *-e-* (nominative singular in *-es*), the compound adjective ends in *-us*, *-a*, *-um:* e. g.

per-di-us (dies, *day*), *lasting all day;*
levi-fid-us (fides, *credit*), *of slight credit;*
per-fid-us (fides, *honor*), *treacherous*, but
ex-spes (spes, *hope*), *hopeless.*

18 3. If the final member is a noun of the third declension, with stem ending in *-i* or in a consonant, the compound adjective will have the form and inflection of its final member: e. g.

multi-fori-s (fori-s, *door), many-doored*[1];
semi-cani-s (cani-s, *dog), half-dog;*
multi-cauli-s (cauli-s, *stalk), many-stalked;*
tri-dens (dens, dent-is, *tooth), three-toothed;*
bi-frons (frons, front-is, *brow), two-browed;*
in-quies (quies, quiet-is, *rest), restless;*
per-nox (nox, noct-is, *night), lasting all night;*
dis-cors (cors, cord-is, *heart), disagreeing;*
multi-color (color, color-is, *color), many-colored;*
bi-pe(d)s (pes, ped-is, *foot), biped;*
se-grex (grex, greg-is, *flock), separate;*
multi-radix (radix, radic-is, *root), many-rooted.*

19 NOTE.—Compounds of genus have either -genus, -a, -um, or -gener-us, -a, -um, or -gener-is, -e: e. g. multi-genus, -a, -um, or multi-generus, -a, -um, or multi-generis, -e, *of many kinds.*

20 4. If the final member is an adjective, it will suffer no change in entering into composition: e. g. per-magnus, *very great;* multi-potens, *very powerful;* semi-nudus, *half-naked;* semper-vivus, *ever-living.*

21 5. If the final member is a verbal root, it will simply add the case-ending of the adjective—in the nominative either
22 (*a*) *-s* (subject to the phonetic laws), or (*b*) *-us*, *-a*, *-um*— directly to the root: e. g.

(*a*) parti-cep-s (cap-ere, *take), taking part;*
morti-fer (fer-re, *bring), death-bringing;*
sacri-fecs (x) (fac-ere, *make), sacrifice-making;*
(*b*) magni-fic-us (fac-ere, *make), great-making;*
perterri-crep-us (crep-ere, *rattle), terribly rattling;*
male-vol-us (vol-o, *wish), ill-wishing;* so bene-vol-us, bene-fic-us, etc.

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[1] The analogy of the *o*-declension has made itself felt here also and we have multi-forus side by side with multi-foris.

The formulæ for making the various classes of adjectives are as follows:

| | | Prefix + | Noun-stem + | (Stem-vowel) + | Case-ending |
|---|---|---|---|---|---|
| 23 | 1. | im- | berb(a)- | i- | s, *beardless;* |
| | | ve- | san- | u- | s, *mad;* |
| | | de- | men(t)- | | s, *mad;* |
| | | per- | noc(t)- | | s, i. e. per-nox, *lasting all night;* |
| | | bi- | pe(d)- | | s, i. e. bi-pes, *biped;* |
| | | se- | greg- | | s, i. e. se-grex, *separate.* |

| | | Adjective-stem + | (Stem-vowel) + | Noun-stem + | (Stem-vowel) + | Case-ending |
|---|---|---|---|---|---|---|
| 24 | 2. | magn(o)- | | anim- | u- | s, *magnanimous;* |
| | | miser(o)- | i- | cor(d) | | s, *compassionate;* |
| | | mult(o)- | i- | mod- | u- | s, *manifold.* |

25 (*a*) The NUMERALS, as first member of compounds, deserve especial mention:

(1) unus follows the general rule and appears as uni-: e. g.

uni-color, *having one color;*
uni-formis, *uniform.*

(2) du-o appears as a prefix in the form of either du-or bi-: e. g.

| | | |
|---|---|---|
| du-plex, *double,* | but | bi-pes, *biped;* |
| du-plus, *double,* | | bi-cornis, *two-horned;* |
| du-bius, *doubtful,* | | bi-lobus, *two-lobed.* |

(3) tres always appears as prefix tri-[1]: tri-color, *three-colored;* tri-cornis, *three-horned;* tri-fasciatus, *three-striped,* etc.

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[1] Except in tre-decim, tre-centi (and their derivatives) and tressis.

(4) quattuor always appears in the form of a prefix, regularly quadri-cornis, *four-horned;* quadri-punctatus, *four-spotted;* quadri-dentatus, *four-toothed;* but influenced by the form and sound of quattuor and quartus, that quadri- may also appear as quadru-: e. g. quadru-manus, as well as quadri-manus, *four-handed;* quadru-pes as well as quadri-pes, *quadru-ped;* etc. Elision will, of course, take place when the second member begins with a vowel: e. g. quadr-angulus, *quadrangle.*

(5) From quinque on, the indeclinable numerals are simply prefixes, suffering no change when they enter into composition, subject, of course, to the usual phonetic laws[1]: e. g. quinque-libris, *five-pound;* sex-punctatus, *six-spotted;* septem-flu-us, *sevenfold-flowing;* octo-punctatus, etc. The declinable numerals of the higher orders are treated like other adjectives, while centum also may follow the same analogy making centi-peda, *hundred-footed;* centi-manus, *hundred-handed;* but also centum-peda; centuplex; etc.

| | | Noun-stem + | (Stem-vowel) + | Verbal-root + | (Stem-vowel) + | Case-ending | |
|---|---|---|---|---|---|---|---|
| 26 | 3. | magn(o)- | i- | fic- | u- | s, | *great-making;* |
| | | fun(i)- | | ambul- | u- | s, | *rope-walking;* |
| | | sacr(o)- | i- | fec- | | s, | *sacrifice-making;* |
| | | part- | i- | cep- | | s, | *sharing;* |
| | | mort- | i- | fer, | | | *death-dealing.* |

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[1] 5. quinque- is the rule; but the rule is not meant to include the compound numerals like quin-decim, quinqua-ginta, quin-genti, etc., nor strange forms like quincu-plex and quincu-pes, which are obviously formed after the analogy of quadru-plex and quadru-pes.

6. ses-centi, se-mestris and their derivatives, conform to the rule, while se-pes is made after the analogy of se-mestris.

7. Besides septem- we find sometimes septu- and septi-, which arose from analogy with quadru- and quadri-, octu- and octi-; or possibly

| | Prefix + | Verbal-root + | (Stem-vowel) + | Case-ending |
|---|---|---|---|---|
| 27 4. | in- | iug- | i- | s, *unyoked;* |
| | se- | cur- | u- | s, *careless.* |

28 5. Verbs are rarely used as first member of a compound; when they are so employed, their stem vowel appears as -i-, either from a natural weakening or from analogy with stems that do suffer such weakening: e. g.

horri-ficus (horre-re, *dread*, + fac-ere, *make)*, *horror-stirring;*
posci-nummus (posc-ere, *ask*, + num-mus, *coin)*, *begging;*
terri-ficus (terre-re, *frighten*, fac-ere, *make)*, *terror-causing;*
perterri-crepus (perterre-re, *terrify*, crep-ere, *rattle)*, *terribly-rattling.*

29 6. Adverbs may be prefixed to almost any adjective without affecting the form: semper-vivus, *ever-living;* bene-volens, *well-wishing;* male-dicens, *evil-speaking;* etc.

## GREEK COMPOUNDS.

The construction of compound words is an art; the consummate mastery of that art is attainable or attained only in the language of Greece. The Germans pile words together in a convenient way and call them compounds, but they are inartistic and artificial. Sanskrit is incomparably richer in compositions than either Greek or German, or both together,

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septu- was influenced by septu-aginta, and septi- is the natural weakening of septu-.

8. octo- is the rule; but when octō became octŏ, it naturally followed the course of the *o-* declension and became first octu- and then octi-.

9. novem- and noven- are both in use and both regular; noven is the older form of the word: e. g. noven-dialis, *of nine days;* November, *the ninth month.*

but those great mountains of words massed one upon the other—a single word often translatable only by a long, involved sentence—are no more to be compared artistically with the Greek compounds than the hundred-handed Vishnu is to be compared with the Hermes of Praxiteles.

30 In forming New Latin compounds of Greek elements there are, just as in the case of Latin compounds, two possibilities: (1) that the word formed will be a noun; (2) that the word formed will be an adjective. Which it will be depends entirely upon the will (and, perhaps, the skill) of the coiner. The rules in either case might be formulated thus:

## I. Nouns.

31 1. We may find the Greek compound already borrowed entire or manufactured by the Romans and take it just as it stands in the Latin lexica. [Most words of that kind available for generic names in Zoology or Botany have already been found and used.]

32 2. We may take the compound as it exists in Greek and simply transliterate it into Latin letters.[1]

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33 [1] The accepted transliteration of the Greek letters into Latin is as follows:

| | | | | | |
|---|---|---|---|---|---|
| α | a | ι | i | ρ | r (ῥ rh; ρρ rrh) |
| β | b | κ | c | σ | s |
| γ | g | λ | l | τ | t |
| δ | d | μ | m | υ | y |
| ε | e | ν | n | φ | ph |
| ζ | z | ξ | x | χ | ch |
| η | e | ο | o | ψ | ps |
| θ | th | π | p | ω | o |

The rough breathing ' is represented by h, the smooth breathing ' is taken for granted and not represented in Latin. Final -ος and -ον, of the second declension, are represented by -us and -um. But final -ως is, of course, rendered by Latin -os. This distinction is an obvious one, and yet the error of transliterating -ως by -us is one into which even the best may fall. For instance, Dr. Gill, in his address before the American Association for the Advancement of Science ("Science," Vol. IV, p. 587), protests against the rule as

34 3. We may take simple Greek words and manufacture of them the compound as it would have existed in Greek and then transliterate it into Latin. The manufacture will take place in accordance with the remaining formulæ.

35 4. If the final member of a *nomen compositum* is a noun, the compound will have the form and gender and inflectional stem of that noun: e. g.

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just given and says: "In accordance with such rules, Rhinoceros has been turned into Rhinocerus. But Rhinoceros was admitted into classical Latinity, and with it the corresponding oblique cases, Rhinocerotis, etc.; in fact, the word was current in the language of description, satire, and proverb—as when used by Juvenal for a vessel made of the horn, or by Lucilius for a long-nosed man, or by Martial in the proverbial expression, 'Nasum rhinocerotis habere'; i. e., *to turn the nose up*, as we should say. These authorities are good enough for me." Most naturally; for they are true to the law! Dr. Gill is unfortunate in his choice of example. Rhinoceros is correct, according to rule, and Rhinocerus is wrong; the spelling -us does not occur in any classical author (except in a false reading in Lucilius, where -os is now read). Of course, there can be no question about the existence of forms in -os for Greek -*ος* and -on for -*ον* in a certain class of writers of the Silver Age, when, according to that same Juvenal, Rome was more Greek than Latin. Apuleius occasionally so transliterates; but it is simply one of his many Greek mannerisms. Pliny the Elder is responsible for the most of the transgressions of that law which are to be found in the dictionaries; his reason for such violation of the Latin law is found in his desire to present the technical or scientific words of his Greek original in an untranslated, unchanged form. The same phenomenon, with the same reason underlying, is to be found in the Church Fathers. And so we have, hammo-chrysos, hady-osmos, ophidion, gingidion, and many more; most of them, as I said, are Pliny's Latin, but Pliny's solecisms or mannerisms should not be good enough for any one when a better than Pliny (in point of Latinity, at least) can be found; and the law both before and after Pliny was: Greek -*ος* is Latin -us, and Greek -*ον* is Latin -um.

The diphthongs:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *αι* | æ | *αυ* | au | *υι* | yi | *ῃ* | e |
| *ει* | e or i | *ευ* | eu | *ᾳ* | a | *ῳ* | o |
| *οι* | œ | *ου* | u | | | | |

ai and oi for *αι* and *οι* before another vowel appear only in a few proper names, as *Achaia*, *Troia*, etc., and therefore do not concern us. The strict Latin orthography cannot be too rigorously insisted upon; consistency will in no other way be obtainable.

anthropo-latra,-ae, masc. (-λάτρης,-ου, masc., stem λατρα-), *man-worshiper;*
cerco-pithecus,-i, fem. (πίθηκος,-ου, fem.), *a monkey with a tail;*
chamaer-ops,-opis, fem. (ὦψ, ὠπ-ός, fem.), *the wall-germander;*
dia-gramma,-grammatis, neut. (γράμμα, γράμματος, neut.), *diagram;*
dasy-pus,-podis, masc. (πούς, ποδός, masc.), *a kind of rabbit;*
chamae-cyparissus,-i, fem. (κυπάρισσος, stem κυπαρισσο-, fem.), *cypress;*
aego-ceras,-ceratis, neut. (κέρας, stem κερατ-, neut.), *goat's horn;* so also
rhync-ops,-opis, fem.; cyclo-stoma,-stomatis, neut.; hippo-potamus, etc., etc.

36 The gender and stem of the compound are the same as
those of its final element; the genitive singular of the com-
37 pound is formed in the same way upon that stem; and if
patronymics were to be formed from such words, they
would be made by adding -idae or -inae to the stem[1]: e. g.
anthropo-latr-idae, chamaer-op-idae, dasy-pod-
idae, aego-cerat-idae, rhynch-op-idae, cyclo-
stomat-idae, etc.

There are a few apparent exceptions to this in our classical lexica, but they are only apparent: e. g. opisthodomus, although derived — borrowed directly — from ὀπισθόδομος, masc., is given (correctly?) as feminine. Δόμος, when transcribed into Latin letters, is identical in form with Latin domus, fem. (which is not derived from the Greek but a genuine Latin word), and the gender would naturally, in the mouths of the people, be changed by the analogy of the Latin word.

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[1] If the stem ends in a vowel, it will, of course, suffer elision before the suffix *-idae.* The only other patronymic suffix in Greek is -ίων, but it is of rare occurrence except in proper names: e. g. στρουθ-ίων, *ostrich;* πορφυρ-ίων, *the purple coot;* and a few others.

No regard needs to be paid to the Latin patronymics. The Romans had no patronymic formation of their own, and when they came to borrow from the Greek, their lack of consistency in following their models introduced a chaos, out of which no rules can be deduced for our guidance.

The same danger threatened all the Greek derivatives that became thoroughly Latinized and entered into the language of the people; many succumbed, and yet not so many as one would naturally expect. Twenty-five or thirty will exhaust the list: e. g. the catapult is a Roman rather than a Greek implement of war, and so we are not surprised to find cata-pulta, -ae, fem., although it owes its origin to *κατα-πέλτης,-ου*, masc. Dia-dema, dogma, schema, etc., were looked upon as neuter nouns and inflected

dia-dema, -demat-is, -demat-i,
dogma, dogmat-is, dogmat-i,
schema, schemat-is, schemat-i, etc.,

or were considered feminine and inflected

diadema, diademae,
dogma, dogmae,
schema, schemae, etc.,

according as they were felt as genuine Latin words or as Greek derivatives. Cicero took pains to show that he thought dogma a Greek word by writing it with Greek letters, *δόγμα*. So also we find oxy-gala, gen. oxy-galact-is, neut., and also oxy-gala, -ae, fem., from Greek *ὀξύ-γαλα,-γάλακτος*, neut.; cata-rrhactes, -ae, masc., and cata-rrhacta, -ae, fem., from Greek *κατα-ρράκτης,-ου*, masc.; etc. In almost every instance of change of gender and inflection, we find, side by side with the Latin change, Latin forms preserving the gender and inflection of the Greek.

38 (*a*) The gender of the genus name, when it is made a noun, depends, therefore, not on the termination, but upon the gender of the noun forming the final element of the compound.

This rule is the only one that can have any philological basis. It is deduced from the practice of the classical word-makers and from the practice of scientists from Linnæus down: e. g. (the instances cited on p. 129); from Linnæus, *Systema Naturæ*, I$^{12}$: Didelphis virginiana, Rhynchops nigra, Ophidion barbatum, etc. The variations on the part of naturalists from this rule are due either to arbitrariness or misunderstanding: e. g. Gnathypops rhomaleus, Hypsipops rubicundus, and others of the sort were made in the supposition that ὤψ was a masculine noun; Hypognathus serenus, in the idea that γνάθος was masculine; so Hybopsis hyostomus, and many more.

39 NOTE.—The theory has been advanced and emphasized that all these compound names are adjectives, with a noun understood.[1] That theory, if rigorously insisted upon, will not leave a single compound noun in the whole Greek language. It will hold good in the case of some but not of all, by any means. *Αἰνο-λέων*, *μικρο-πολίτης*, *τρωγλο-δύτης*, *κυνόσ-ουρα*, *προ-κύων*, *λεοντο-πέταλον*, *ἑρπ-άκανθα*, *Διόσ-κουροι*, *σταφυλό-δενδρον*, *χαμαί-πιτυς*, *πρό-ναος*, *ξιφο-μάχαιρα*, *πιτυο-κάμπη*, *χην-αλώπηξ*, and any number more are just as good nouns as were ever produced, and the same is true of the names of genera, as both scientists and philolo-

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[1] This theory seems to originate with one Herrmannsen, who is quoted as saying: Vocabula composita Graecæ originis, quorum terminalis radix generis neutralis, in *α* exiens, genitivo *-ατος* flectitur, nonnisi adjectivo sensu adhibentur. Hinc si neutralia numero plurali obveniunt, ut Adeloderma, Cricostoma [sing. *-um*, vel *-on*], terminentur genitivo *-orum;* sin autem singulari numero, ut Amphidesma, Cyclostoma, feminini erunt generis, et declinabimus "Cyclostomæ." Documento sint veterum nomina *ὀστραχόδερμα* [which is simply neuter plural of the adjective *ὀστραχόδερμος*, see §§ 44 and 55], *τρίστομος*, *ἄδεσμος*.—Quoted by Dr. Gill, National Academy of Sciences, Vol. VI, Sixth Memoir, p. 129.

Herrmannsen's rule is all very well, with the exception of the two words nonnisi adjectivo; the falsity of this assumption is abundantly proved by a host of examples, such as dia-dema, genitive diadematis; dia-phragma, genitive, diaphragmatis; epigramma, genitive, epigrammatis; emblema, genitive, emblematis, etc., etc. See §§ 35–44. The possibility of an adjective formation of the sort assumed by Herrmannsen is recognized in § 44 and more fully explained in § 55.

gists look at them. If we could assume that they were adjectives, it would puzzle one to discover why one piscis is feminine, another masculine and a third neuter. It is the same with aves, reptilia, plantae, etc.; and the word chosen for the assumed adjectives to agree with would be arbitrarily chosen and would have little chance of corresponding with the idea in the mind of the coiner when he named his genus.

40 To say that epi-gramma, melo-drama, acro-polis, macro-cosmus, leonto-cephale, chaen-alopex, Helles-pontus, pyx-acantha, hippo-dromus, and hundreds of others are not nouns, but adjectives used substantively with some imaginable word understood, is no less absurd than to deny that cyclo-stoma, di-delphys, etc., may be nouns of the same sort and subject to the same laws. And yet that theory which would make adjectives of all these words tells us that even mega-therium is not a noun but a neuter adjective modifying animal or monstrum understood, and that it is subject to the inflection megatherius, megatheria, megatherium, etc.! It is, therefore, properly derived, we are informed, not from *μέγα+θηρίον* directly, but from a *μεγα-θήριος* sc. *θήρ*, '*a great-beastly animal.*' That is, to be sure, a perfectly legitimate course to take in order to get megatherium, but it is no more likely that it was obtained in that way than it is that the discoverer of cyclo-stoma did not simply put together *κύκλος+στόμα*, but first built an adjective *κυκλό-στομος,-ον*, then turned that into Latin cyclo-stomus, -um, and then arbitrarily manufactured a feminine cyclo-stoma to agree with piscis, masculine, understood! The classical precedent for forms in -stomus, masc. and fem., -stomum, neut., is poly-stomus, masc. and fem., poly-stomum, neut. The only rational way to form either would be *μέγα+θηρίον* and *κυκλο-+στόμα*. And as cyclostoma goes, so must go the rest of the words in *-stoma*,
41 *-soma*, etc. In general, it is arbitrary and inexact to make adjectives of three endings in Latin out of Greek adjectives of two endings. The old Latinists used the form in -us for

both masculine and feminine, and -um for the neuter; e. g. curo-troph-us (-os), masc. and fem., curo-troph-um (-on), neut.; dory-phorus, masc. and fem., dory-phorum, neut.; disco-phorus, masc. and fem.; eu-petalus, masc. and fem.; poly-stomus, masc. and fem., -um, neut. The only exception I find given in the Latin dictionary is di-somus, -a, -um; but that is erroneous and should read disomus, -um.

42 5. Family names formed from neuter names of genera in -stoma, -soma, etc., should end in -atidae not in -idae; for the stem of those words ends in -at, Greek -ατ. It is so in Latin (see p. 129): e. g. dia-phragma, gen. dia-phragmat-is, epi-gramma, gen. epi-grammatis, em-blema, gen. em-blemat-is, etc.

43 NOTE.—The family name from forms in -stomatus, -a, -um, would appear in the same form as that from -stoma, -stomat-is.

44 6. Family names formed from adjectives (used substantively) in -stomus or -stomum, -somus or -sonum, etc., end in -idae, not in -atidae. Thus Catostomus, Catostomidae.

## II. ADJECTIVES.

45 As a matter of course, this division will comprise by far the largest part of all Greek compounds, but not by any means all of them. Many of the compounds are genuine nouns (see §§ 39–41), and all the adjectives may be used as nouns.

46 In forming compound adjectives from substantives (nouns, adjectives and participles), it is not the familiar, nominative singular form of the noun, adjective or participle that is used, but the stem.[1] If the first element is a substantive with a stem ending in a vowel and the second begins with a vowel, the stem-vowel of the first element is, of course,

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[1] See § 5, with foot-note 1.

47 elided[1]; and, at the same time, if such elision brings a simple surd (*κ*, *π*, *τ*) up against a vowel affected by a rough breathing, that simple surd will become the corresponding aspirate (*χ*, *φ*, *θ*). If, on the other hand, the second element begins with a consonant, the vowel stands, and the rule is that all *α*-stems follow the analogy of the *ο*-stems and
48 change their vowel to *-ο-*. When, however, the stem of the first member ends in *-ι* or *-υ*[2], the same analogy has forced itself in and *-ο-* is added to the stem of the first as a connecting-vowel between it and the second member of the compound[3]: e. g. *ἐρυθρ(ο)-όφθαλμος* (*ἐρυθρός*, *red*, + *ὀφθαλμός*, *eye*), *red-eyed; ἡμερο-δρόμος* (*ἡμέρα*, + *δρόμος*, *running*), *one who runs all day; θύρ(α)-αυλος* (*θύρα*, *door*, + *αὐλέω*, *lodge*), *living out of doors;* but *θυρ-ο-κόπος* (*θύρα*, *door*, + *κόπτω*, *knock*), *knocking at the door; δεχ-ἥμερος* (*δέκα*, *ten*, + *ἡμέρα*, *day*), *ten-day; νυχθ-ἥμερ-ος* (*νύξ*, stem *νυκτ-*, *night*, + *ἡμέρα*, *day*), *night and day; μελαν-ο-κέφαλος* (*μέλας*, *black*, stem *μελαν-*, + *κεφαλή*, *head*), *black-headed; λεοντ-ο-κέφαλος* (*λέων*, stem *λεοντ-*, *lion*, + *κεφαλή*, *head*), *lion-headed; ἱμαντό-πους* (*ἱμάς*, stem *ἱμαντ-*, *strap*, + *πούς*, *foot*), *leather-footed; ὀφι-ο-κέφαλος* (*ὄφι-ς*, *serpent*, + *κεφαλή*, *head*), *snake-headed; πολι-οῦχος*, i. e. *πολι-ό-εχος* (*πόλι-ς*, *city*, stem *πολι-*, + *ἔχω*, *hold*), *city-holding; ἰχθυ-ο-πώλης* (*ἰχθύ-ς*, *fish*, + *πωλέω*, *sell*), *fish-monger*. But when the final *υ* of the stem is part of a

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[1] Sometimes contraction takes place: e. g. *κακοῦργος* (*κακός* + **ἔργω*), working ill; *εὐνοῦχος* (*εὐνή*, bed, + *ἔχω*, tend), eunuch. This would be the natural phonetic course for such combinations to follow, but it is the exception, rather than the rule, for them to do so.

49 [2] This rule applies to nouns only; all adjectives with stems in *-υ*, when figuring as first member of a compound, appear as bare stem without any connecting-vowel: e. g. *βραχύ-πους*, short-footed; *βραχύ-ουρος*, short-tailed; *βραδύ-νους*, slow of thought; *ἡδύ-οσμος*, sweet-smelling; *ὠκύ-πους*, swift-footed; and all the hosts of words beginning with *πολυ-*.

50 [3] *α*, *ε*, *ι*, and *η* occur so rarely in the middle of compound words, even before a consonant (and then, too, for the most part, in poetry), that for our purposes we may disregard them entirely. Still, good classical precedents may be found for the use of any one of them; *ἰχθύς*, e. g., appears in the Greek lexicon as the first member of compounds thirty-one times with an *–ο–* over against fourteen times without the *–ο–*, while the compounds of *ὄφις* all have the *–ο–* vowel.

diphthong, the connecting-vowel is never used: e. g. *ναυαγός (ναῦ-ς, ship,+ √ἀ̄γ-, ἄγ-νυ-μι, break), ship-wrecking; βου-κέφαλος (βοῦ-ς, ox,+κεφαλή, head), ox-head; βου-κράνιον, ox-skull.*

51 The second word also is so powerfully influenced by the same analogy, that a large majority of all compound adjectives take the inflection of the *-ο-* declension, with two endings: *-ος*, masc. and fem., *-ον*, neuter. These usually go into Latin as -us, masc. and fem., and -um, neut.; rarely the feminine has a separate form in -a, and the neuter a form in -on. Some have *-ης,-ες*, and some take the original form of the final member. The rules for the three respective cases might be drawn as follows:

52 1. When the final member of the compound is (*a*) a substantive of the first declension with stem ending in *-α* (nominative in *-ης* or *-ας* masc., *-α* or *-η* fem.), or (*b*) of the second declension with stem ending in *-ο* (nominative in *-ος*, masc. or fem., *-ον*, neut.), or (*c*) if the final member is made directly from a verbal root, the compound adjective ends in *-ος*, masc. and fem., *-ον*, neut.

(*a*) *ὑπερ-βόρε-ος (βορέ-ας, north), beyond the north;*
*βραχυ-ουρ-ος (οὐρά, tail), short-tailed;*
*οἰδί-κνημ-ος (κνήμη, shin), swollen-shinned;*
*νυχθ-ήμερ-ος (νυκτ-*, stem of *νύξ, night,+ἡμέρα, day), night and day;*
*κυνο-κέφαλ-ος (κυν-*, stem of *κύων, dog,+κεφαλή, head), dog-headed;*

(*b*) *τρι-δάκτυλ-ος (δάκτυλο-ς, finger,) three-fingered;*
*λευκ-όφθαλμ-ος (ὀφθαλμό-ς, eye), white-eyed;*
*χρυσό-πτερ-ος (πτερό-ν, wing), gold-winged;*
*μακρό-κεντρ-ος (κέντρο-ν, sting), long-stinged;*

(*c*) *ὑπ-ήκο-ος, (ἀκόϝω, hear), obedient;*
*θηρ-ο-τρόφ-ος, (τρέφω, breed), animal-breeding;*
*λιθο-φάγ-ος (√φαγ, φαγεῖν, eat), stone-eating;*
*ἀνθο-λόγ-ος (√λ$^{ε}/_{ο}$γ, λέγω, gather), flower-gathering.*

53 2. When the final member of the compound is a substantive of the third declension with the stem ending in any
consonant except -*ν*, -*ρ*, -*δ*, or -*ες* (and occasionally also
even then), the compound adjective (1) usually follows the.
same analogy and ends in -*ος*, masc. and fem., and -*ον*,
54 neut., or (2) retains the third declensional form of the final
member:

(1) *ἔν-σαρκ-ος* (*σάρξ*, stem *σαρκ-*, *flesh*), *incarnate;*
*ἀ-χρώματ-ος* (*χρῶμα*, stem *χρωματ-*, *color*), *colorless;*
*πολύ-χειρ-ος* or *πολύ-χειρ* (*χείρ*, *hand*), *many-handed;*
*πάμ-μηνος* (*μήν*, *month*, stem *μην-*), *lasting through all the month;*

(2) *μίκρ-ωψ* (*ὤψ*, stem *ὠπ-*, *eye*), *small-eyed;*
*ἐρι-βῶλαξ* (*βῶλαξ*, stem *βωλακ-*, *clod*), *with big clods;*
*μακρό-χειρ* (*χείρ*, stem *χειρ-*, *hand*), *long-handed;*
*δυσ-έρως* (*ἔρως*, stem *ἐρωτ-*, *love*), *cherishing an unhappy love;*
*ὀλεσί-θηρ* (*θήρ*, stem *θηρ-*, *beast*), *beast-destroying.*

55 (*a*) When the final member is a neuter noun ending in -*μα* (stem ending in -*ματ-*), the compound adjective properly ends in -*ματ-ο-ς*, as in the rule just given, or (as those words not infrequently in composition shorten the stem from -*ματο-* to -*μο-*[1]) in -*μος*, or we may have both the longer and shorter forms side by side; e. g.

*τρι-σώματ-ο-ς* and *τρί-σωμ-ο-ς*, *three-bodied;*
*ἀ-σώματ-ο-ς* and *ἄ-σωμ-ο-ς*, *bodiless;*
*ἀ-δέρματ-ο-ς* and *ἄ-δερμ-ο-ς*, *skinless;*
*ἀ-χρώματ-ος* and *ἄ-χρωμ-ο-ς*, *colorless.*

Linnæus has forms to which the prototypes would be *ἀνώ-στομ-ο-ς*, *πολύ-νημ-ο-ς*, *χρυσό-στιγμ-ο-ς*, *χρυσό-στομ-ο-ς*, *αἱμό-στομ-ο-ς*, *γονό-στιγμ-ο-ς*, *ἀργυρό-στομ-ο-ς*.

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[1] Perhaps following the analogy of words like *γράμμα,-ατος*, with its parallel *γραμμή,-ῆς*, from which we have *γραμμο-ειδής*, etc.; cf. *σπερμο-βολέω*, *σπερμο-λόγος*, *δερμό-πτερος*, *σωμ-ασκέω*, *σωμ-εραστής*, etc.

The shortened forms may occur also when these words are used as first members of compounds: e. g.

| | | | |
|---|---|---|---|
| σπερματ-ο-λόγ-ο-ς | | and | σπερμ-ο-λόγ-ο-ς, *seed-collecting;* |
| σπερματ-ο-φάγ-ο-ς | | and | σπερμ-ο-φάγ-ο-ς, *seed-eating;* |
| σωμάτ-ηγ-ο-ς | | but | σωμ-εραστής; |
| αἱματ-ό-πους | (L.) | but | αἱμ-ό-πτερ-ο-ς (L.); |
| αἱματ-ώδης | (L.) | but | αἱμ-ό-στομ-ο-ς (L.). |

56 (*b*) When dealing with this class of neuter nouns, therefore, we may be entirely justified in using whichever form may happen to suit our fancy, and say dermato-, spermato-, haemato-, somato-, etc., or dermo-, spermo-, haemo-, etc., as we will. Numerically, the Greek lexicon reveals a preference for the longer form as first member of a compound, and for the shorter form in the final member.

(*c*) For the inflection of these adjectives and the formation of family names derived from them and from the corresponding nouns, see pp. 127–132.

57 3. When the final member is a substantive of the third declension, with a stem ending in -ν, -ρ, or -δ (which is always dropped by law before the -ς of the nominative singular), the compound adjective usually retains the form and inflection of the last member: e. g.

κακο-δαίμων, *possessed of a bad spirit;*
αὐτό-χθων, *sprung from the earth itself;*
φιλ-έλλην, *Greek-loving;*
πολύ-χειρ, *many-handed;*
ἄ-παις (ἀ- privative +παί(δ)ς, *child*), *childless;*
ῥίψ-ασπις (ῥίπ-τω, *throw*,+ἀσπίς, stem ἀσπιδ-, *shield*), *throwing away one's shield;*
ἄ-πους (ἀ- privative +πούς, for +*πο(δ)ς, *foot*, *footless;*
ἱμαντ-ό-πους (ἱμάς, stem ἱμαντ-, *leather strap*, +*πο(δ)ς, *foot*), *leather-footed;* so also λαγώ-πους, *hare-footed;* βραδύ-πους, *slow-footed;* ἐρυθρό-πους, *red-footed;* χλωρο-πους, *green-footed;* etc.

58 (*a*) All words in -pus (Greek -πους) have the stem in -pod; the genitive ends as in Latin in -pod-is, the plural in -pod-es. The family name will, therefore, end in -pod-idae. The Latin lexicon reveals forms like

| | | | |
|---|---|---|---|
| echino-pus, | gen. -pod-is; | chytro-pus, | gen. -pod-is; |
| haemato-pus, | " -pod-is; | clino-pus, | " -pod-is; |
| himanto-pus, | " -pod-is; | Oedi-pus, | " -pod-is; |
| lago-pus, | " -pod-is; | tri-pus, | " -pod-is. |

There is no exception; corono-pus has genitive -podis, but accusative -pum. Poly-pus, -i, has also Greek πολύπος, πολύπου, as archetype.

59 (*b*) In the same way the words in -n and -r (Greek -ν and -ρ) have the genitive in -n-is and -r-is, the plural in -n-es and -r-es, and the family names in -n-idae and -r-idae.

60 4. When the final member is a substantive of the third declension, with a stem ending in -ες (nominative in -ης, masc. or fem., -ος, neut.), the compound adjective will end in -ης, masc. and fem., and -ες, neut.: e. g.

δι-έτης (ἔτος, stem ἐτεσ-, *year*), *biennial;* so τρι-έτης, *triennial;*
λυσι-μελής (μέλος, stem μελεσ-, *limb*), *limb-relaxing;*
νη-κερδής (κέρδος, stem κερδεσ-, *gain*), *bootless.*

Linnæus seems to use as adjectives the noun forms oxyrincus (*sic*) (pp. 512, 395), gono-ryn-chus (p. 528), callo-rynchus (p. 402), syn-gnathus (p. 416).

61 (*a*) When the last member of such a compound is εἶδος, preceded by an -ο-, the -ο-+ειδες may contract to -ωδες: e. g.

τριχ-ο-ειδής or τριχ-ώδης, *hairlike;*
κητ-ο-ειδής or κητ-ώδης, *cetacean;*
κυκλ-ο-ειδής or κυκλ-ώδης, *cycloid;*
γογγυλ-ο-ειδής or γογγυλ-ώδης, *roundish.*

62 5. When the final member is a neuter noun of the third declension with stem ending in *-ατ-* (nominative singular in *-ας*), the compound adjective will end in *-ως* (contracted from *-α(τ)ος*) for the masc. and fem., and *-ων* for the neut.; but (*a*) sometimes it follows the analogy of the adjectives in *-ος*, *-ον*: e. g.

*γλυκύ-κρεως,-ων* or *γλυκύ-κρε-ος, -ον, sweet-meated* (*κρέας*; stem, *κρεατ-*);
*μονό-κερως* or *μονό-κερος, one-horned* (*κέρας*; stem,*κερατ-*);
*ἀ-γήρως*(*γῆρας, age*), *ageless*; but
*ὀρθό-κερ-ος, upright-horned; ῥινό-κερως, horn-nosed;* etc.

63 6. When the final member is a substantive of the third declension with a stem ending in the vowel *-ι-* or *-υ-* (nominative singular *-ις*,*-υς*, masc. or fem., and *-ι* or *-υ*, neut.), the ending of the compound will appear identical with the form of the final member: e. g.

*σωσί-πολι-ς* (*πόλι-ς, city*), *city-saving;*
*περσέ-πολι-ς* (*πόλι-ς, city*), *city-destroying;*
*ὀφι-όψι-ς* (*ὄψι-ς, look*), *looking like a snake;*
*λιπό-ναυ-ς* (*ναῦ-ς, ship*), *ship-abandoning;*
*δί-πηχυ-ς* (*πῆχυς, cubit*), *two cubits long;*
**ἄ-δελφυ-ς* (*δελφύς, womb*), *wombless;* etc.

64 7. When the final member is a verbal root, it may have
either an active or a passive force; (*a*) if active, the com-
pound may have the simple verbal root with the endings
65 *-ος*, *-ον*; (*b*) if passive, it will usually have the suffix
66 *-τος*; (*c*) it may have the ending *-ης*, which is either
active or passive: e. g.

(*a*) *θηρ-ο-τρόφ-ος* ($\sqrt{\tau\rho^{\varepsilon}/_{o}\phi}$, *τρέφω, breed*), *animal-breeding;*
*ὑλ(α)-ο-τόμ-ος* ($\sqrt{\tau^{\varepsilon}/_{o}\mu}$, *τέμ-ν-ω, cut*),*wood-cutting;*
*οὐραν-ο-σκόπ-ος* (*σκοπ-έω, see*), *sky-gazing;*

(*b*) *κατά-φρακ-τος* (*√φραγ, φράσσω, cover*), *covered over;*
*δορυ-άλω-τος* (*√ἁ̄λω-, ἁλίσκομαι, be taken*), *taken with the spear;*
*ἀ-λεπίδω-τος* (**λεπιδόω, cover with scales*), *not covered with scales;* so
*μακρο-λεπίδω-τος*, *ἄ-γνω-τος*, *'Αρηΐ-φα-τος*, etc.

(*c*) *εὐ-μαθ-ής*, *easily learning*, or *easily learned;*
*ἀ-μαθ-ής*, *not learning*, or *not learned;*
*θεο-σεβ-ής*, *reverencing the gods.*

The principal classes of Greek compound adjectives, the formation of which is concerned in this discussion, are not different from the classes of Latin compounds discussed in §§ 23–29 and will be treated in the same way. They are as follows:

| | | Noun-stem + | Connecting-vowel + | Noun-stem (+ | Connecting-vowel )+ | Case-ending |
|---|---|---|---|---|---|---|
| 67 | 1. | *λεοντ-* | *ο-* | *κέφαλ(α)ο-* | | *ς*, *lion-headed;* |
| | | *ἵππ(ο)-* | | *ουρ(α)ο-* | | *ς*, *horse-tailed;* |
| | | *πάμ-* | | *μην-* | *ο-* | *ς*, *all the month;* |
| | | *κυν-* | *ό-* | *γλωττ(α)ο-* | | *ς*, *dog-tongued;* |
| | | *κυν-* | *ο-* | *κέφαλ(α)ο-* | | *ς*, *dog-headed;* |
| | | *ῥοδο-* | | *δάκτυλο-* | | *ς*, *rosy-fingered.* |

68 The process would be exactly the same for two adjectives combined into one; or for an adjective with an inseparable prefix:

*ἐρυθρό-λευκο-ς*, *reddish white;*
*λευκο-μέλα(ν)-ς*, *black and white;*
*πολύ-χλωρο-ς*, *very green;*
*ἀν-αίτιο-ς*, *not to blame;* *ἄ-σοφο-ς*, *unwise;* etc.

| | | Prefix + | Noun-stem (+ | Connecting-vowel ) + | Case-ending | |
|---|---|---|---|---|---|---|
| 69 | 2. | ἀμφί- | βιο- | | ς, | *amphibious;* |
| | | ἀ- | σώματ- | ο- | ς, | *bodiless;* |
| | | ὑπό- | λευκο- | | ς, | *whitish;* |
| | | ἄ- | δεσμο- | | ς, | *unbound;* |
| | | ἀ- | χρώματ- | ο- | ς, | *colorless;* |
| | | ἡμί- | πτερο- | | ς, | *half-finned.* |

| | | Adjective-stem + | Noun-stem | (+ Connecting-vowel) + | Case-ending | |
|---|---|---|---|---|---|---|
| 70 | 3. | μάκρ(ο-) | ουρ(α)ο- | | ς, | *long-tailed;* |
| | | τρι- | σώματ- | ο- | ς, | *three-bodied;* |
| | | περκνό- | πτερο- | | ς, | *dusky-winged;* |
| | | λευκ(ο-) | ὀφθαλμο- | | ς, | *white-eyed.* |

71 (*a*) Numeral adjectives follow an abnormal course:

(1) Instead of the numeral εἷς, μία, ἕν, in composition, μόνος=*single*, is used: e. g. μονό-γαμος, *married but once;* μονό-ζυξ, *single-yoked;* μονό-κερως, *having but one horn.*

(2) For δύο- there is an inseparable prefix δι- which is always used in compounds: e. g. δι-δάκτυλος, *two-fingered;* δι-όδων, *two-toothed;* δί-πτερος, *two-winged;* δι-έτης, *biennial.*

(3) The stem of τρεῖς, τρία, is τρι-, which is simply prefixed in entering into composition: e. g. τρί-σωμος, *triple-bodied;* τρι-δάκτυλος, *three-fingered;* τρί-γωνος, *three-cornered.*

(4) τέτταρες has also an inseparable prefix form τετρα-: e. g. τετρα-δάκτυλος, *four-fingered;* τετρά-γωνος, *four-cornered;* τετρα-έτης, *quadriennial.*

(5) and (6) *πέντε* and *ἕξ* follow the analogy of *τετρα-* and *ἑπτά*, and make prefixes *πεντα-* and *ἑξα-* respectively: *πεντα-δάκτυλος*, *five-fingered;* *ἑξα-δάκτυλος*, *six-fingered.*

(7) *ἑπτά*, *ὀκτώ*, etc., are simply prefixed without change.

72 NOTE.—Πᾶν in composition is usually treated as a neuter substantive, with stem *παν-* instead of *παντ-*,in an adverbial relation to the other member of the compound: e. g. *πάν-σοφος*, *all-wise*, *παν-σέληνος*, *full-mooned;* *πάμ-μηνος*, *through all the month;* Παν-έλληνες, *the Grecian world;* rarely *παντ-ο-*: *παντ-ο-δαπός*, *all sorts of;* *παντ-ο-πόρος*, *all-traversed.*

| | | Noun-stem | (+ Connecting-vowel) | + Verb-stem | + Connecting-vowel | + Case-ending |
|---|---|---|---|---|---|---|
| 73 | 4. | *αἱμ-* | *ό-* | *ρρο-* | *ο-* | *ς*, *flowing with blood;* |
| | | *τοπο-* | | *γράφ-* | *ο-* | *ς*, *place-describing;* |
| | | *λιθο-* | | *φάγ-* | *ο-* | *ς*, *stone-eating;* |
| | | *οὐρανο-* | | *σκόπ-* | *ο-* | *ς*, *sky-gazing;* |
| | | *βραγχιο-* | | *στέγ-* | *ο-* | *ς*, *gill-covered.* |

| | | Prefix + | Verbal-root | (+ Connecting-vowel) | + Case-ending |
|---|---|---|---|---|---|
| 74 | 5. | *ἄ-* | *τροπ-* | *ο-* | *ς*, *not turning;* |
| | | *ἀνά-* | *βλεπ-* | | *ς*, i. e. *βλεψ*, *looking up;* |
| | | *ἔν-* | *τροφ-* | *ο-* | *ς*, *living with;* |
| | | *ἄ-* | *τομ-* | *ο-* | *ς*, *uncut;* |
| | | *διχό-* | *τομ-* | *ο-* | *ς*, *cut in two.* |

Exceptions to these rules will be found, of course, not only in scientific nomenclature, but even in well approved classics. All that has been attempted here has been to give the rule, leaving the abnormal to take care of itself. As I have given the rule and ignored the exceptions for the most part, even where exceptions are numerous, the laws laid down may be called "Draconian," and censured as being "tinctured with more than Roman severity." But the "frequent laments over the instability of our systematic nomenclature" and the "bitter complaints against those who change names" are called forth in nearly every case by some one's having rebelled against some "Draconian" law. Consistency and correctness can be secured only by following out what is recognized as rule, and will surely be thwarted by adopting strange forms even when sanctioned by sporadic use on the pages of a Pliny. Nothing is good enough but the best, whether in science or language or Latin form for scientific nomenclature; and Pliny, for the last, is not good enough so long as we have something better. I cannot refrain from concluding with the rest of Dr. Gill's paragraph, alluded to above, in which, after objecting so vigorously to what he calls "Draconian" laws and "laws tinctured with more than Roman severity" and urging that "the language of nomenclature should not be bound by rules of strict philology," he declares so unequivocally for humble obedience to the higher law of priority as the only way out of utter confusion: "Frequent are the laments over the instability of our systematic nomenclature; bitter the complaints against those who change names. But surely such complaints are unjust when urged against those who range themselves under laws. We are forcibly reminded by such complaints of the ancient apologue of the wolf and the lamb. The stream of nomenclature has indeed been muddied, but it is due to the acts of those who refuse to be bound by laws or reason. The only way to purify the stream is to clear out all the disturbing elements. In doing so, mud that has settled for a time may be disturbed, but that is at worst anticipating what would have inevitably happened sooner or later. We are suffering from the ignorance or misdeeds of the past. In opposing the necessary rectifications and the enforcement of the laws, extremes may meet ; conservatives and anarchists agree. But the majority may be depended upon in time to subscribe to the laws, and the perturbed condition will then cease to be."

We may recognize the law of priority as absolute, and retain the many monstrous and misspelled names to be found on the records of natural history, just as their makers left them. They are historic facts and serve to mark the group of animals or plants to which they apply, but these misshapen forms of words are not ornamental and they are unworthy of scholars. It is to be hoped that, in future, greater care may be taken to make words that give correctly the idea the author may have intended. Such words as *Felichthys*, *Lepomis*, *Semotilus* demand the constant apology of those who use them, while words like *Zalophus*, *Ericymba*, *Hylocichla* are a pleasure in themselves to those who understand their meaning. It costs no more to frame a name properly than to leave it a monstrosity.

If this paper shall serve as a stepping-stone toward the attainment of correctness and uniformity in the framing of names of classical origin, its purpose will be fully met.

CONTRIBUTIONS TO BIOLOGY
FROM
THE HOPKINS SEASIDE LABORATORY
OF THE
LELAND STANFORD JR. UNIVERSITY.

## XI

# A Morphological Study of Naias and Zannichellia.

BY
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## PREFATORY NOTE.

This memoir is the eleventh of a series designed to illustrate investigations and explorations connected with the Hopkins Seaside Laboratory, an adjunct of the biological laboratories of the Leland Stanford Junior University. These investigations have been carried on by means of the assistance given by Timothy Hopkins, Esq., of Menlo Park, California. The memoirs forming this series are published in the Proceedings of the California Academy of Sciences, the present edition being a reprint from these proceedings.

OLIVER P. JENKINS,
CHARLES H. GILBERT,
*Directors Hopkins Laboratory.*

Date of publication, June 5, 1897.

# A MORPHOLOGICAL STUDY OF NAIAS AND ZANNICHELLIA.

BY DOUGLAS HOUGHTON CAMPBELL,
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June 4, 1897.

IF ONE examines the enormous mass of literature bearing upon the great group of Angiosperms that has accumulated and that is being rapidly augmented, one must be impressed with the very great preponderance of work of an exclusively descriptive character. Whether one examines descriptive floras or monographs of special groups, the number where the descriptions extend beyond a mere enumeration of external characters is astonishingly small. While this is usually quite sufficient for the mere identification of a plant and for determining its relation to nearly allied forms, it is quite inadequate for settling questions of relationship between more remote groups, and especially those of obscure affinities. The constant addition of new forms to the already immense list of known species but adds to the confusion which exists, and out of which it seems hopeless to expect ever to bring order. What is needed is not so much additions to this great mass of undigested material, as some beginning of a more thorough study of the materials at hand. How greatly would the value of many an important monograph on a genus or family be enhanced did it but include a connected account of the whole life-history of one or two representative forms! Were this done, we should soon have a collection of data upon which to make a beginning, at least, of a classification of the Angiosperms, which would be something more than mere guess work. Such minute histological study of all the phases of development is of especial importance in those simpler groups of both Monocotyledons and Dicotyledons, where the floral parts are very simple, and where doubt arises whether we have to do with structures primitively simple or the result of degradation. The present chaotic condition of taxonomy is beyond question largely due to the superficial methods which are adopted in classification. An inheritance from a former scientific era, these primitive methods are held to with a persistency which does not augur especially well for the future.

The great advances made of late years in microscopical technique, both in regard to preserving and staining methods, and especially the use of the microtome, have been as yet but little utilized by the systematic botanists. While these cannot be expected to be the principal tools of the systematist, they should prove invaluable aids in his work. The improvement in technical methods also makes necessary a revision of much of the older histological work, which is often either inaccurate in detail or incomplete. Many of these older contributions, of course, are of the greatest importance, but all the more is it necessary to correct any inaccuracies which they may contain. Naturally, with the improvement in technique there has been an increasing number of accurate histological studies of the flowering plants, especially investigations bearing upon the development of the reproductive parts. It is these which must serve as the starting point for the accumulation of data for the final classification of the higher plants. It is true that the structure of the flower and fruit of the Angiosperms is of the greatest importance in their classification; but these alone are not sufficient for settling positively questions of affinity, except between nearly related groups. An accurate knowledge of the development and histology of the reproductive parts and embryo is also very important in this connection. Not until very much more is known than at present about the life-history of representatives of all the principal types of flowering plants, shall we be in a position to begin to build up a system of classification which we can hope to be even approximately accurate.

Among the interesting problems awaiting solution is the character of certain simple Monocotyledons. Indeed, the whole question of the relation of this group to the other flowering plants is one about which there is much disagreement. With the hope of perhaps being able to throw some light on this question, and at the same time to call attention to these problems, and perhaps interest other botanists in the same or similar work, the writer decided to begin a series of investigations upon the structure and development of some of the simpler Monocotyledons. The present paper is the first of a series which he hopes to publish from time to time, as the materials become available. While no very startling results have been brought out as yet, nevertheless, a number of interesting and more or less important structural details have been brought to light, which it is hoped will serve for the basis of more extended researches in the future.

How poorly the affinities of the simpler Monocotyledons are understood is at once evident from the extraordinary divergence of opinion among botanists in their arrangement of genera and families. Thus, *Naias* is sometimes included with *Potamogeton* and *Zannichellia* in the family of Naiadaceæ(Morong, 1893); while on the other hand, most botanists at present consider this family to contain only the single genus *Naias*, while *Zannichellia* is placed in the Potamogetonaceæ (Ascherson, 1889); and it has been recently suggested that it should stand as a type of a separate family, Zannichelliaceæ (Schumann, 1892). These instances will serve to show how urgent is the need of a thorough investigation of these doubtful forms, and as the two genera, *Naias* and *Zannichellia*, are structurally among the very simplest of the Monocotyledons, they were selected as the first forms for investigation. Both genera, especially *Naias*, have been examined carefully as to their gross morphology, but the histological details concerning them are very scanty. The most important work done of late years is that of Magnus and Schumann. The former confined his work mainly to *Naias*, although in his last paper (1894) he also gives some details for *Zannichellia;* Schumann (1892) has given a fairly full account of the general development of *Zannichellia;* but owing to his depending entirely upon a study of the external structure and not using sections at all, he has made some serious mistakes in his interpretations of the homologies of the floral structures. Most of the work of the earlier botanists was unfortunately inaccessible to the writer, but in Magnus' first paper (1870) there is a very full and clear résumé of the results of these observations, to which the reader is referred for further details.

The writer has confined himself mainly to a study of the development and histology of the reproductive parts of the plants, as the general structure and histology of the vegetative parts has already been, on the whole, accurately described; nevertheless, it has been found necessary to correct a few points, the most important being the structure of the vascular bundle of *Naias*. The absence of tracheary tissue, which has been supposed to be characteristic of this genus[1], it is found is only apparent, at least in *N. flexilis*, the only species studied. Here tracheids are always found in the young bundles, but are subsequently destroyed by the great elongation of the parts, so that in the fully developed bundle no trace of them is to be found. This will serve as one more instance of the importance of studying the development of the parts as well as their structure when fully formed.

Most of the results here given were obtained from the study of serial microtome-sections. The material was in most cases fixed with one per cent. aqueous solution of chromic acid, and after thoroughly washing was transferred gradually to alcohol, where it remained until wanted. No other reagent employed gave as good results as chromic acid, although material so fixed, unless very thoroughly washed, is apt to offer resistance to nuclear stains. The material was stained *in toto* with Czokor's alum-cochineal, and after dehydrating was imbedded in paraffin. The earlier preparations were passed through turpentine before imbedding, but later xylol was substituted with excellent results, the formula being that given by Zimmermann (1893, p. 33), except that a much shorter time than he gives was found to be sufficient. The series of sections was afterwards stained on the slide with a solution of Bismarck brown in 70 per cent. alcohol. In the study of the embryo-sac of *Naias*, the anilin-safranin method recommended by Schaffner (1896, p. 123) was used to some extent and with good results.

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[1] While Magnus denied the presence of tracheary tissue, he refers to the work of an Italian, Pollini, who claims to have seen it.

## A.—Naias.

The most important contribution to our knowledge of the genus *Naias* we owe to the admirable monograph of the genus by Magnus (1870). In the introduction he has given a very clear and satisfactory résumé of the work done by earlier observers, from Vaillant's account in 1719, up to the time of the publication of his own memoir. He has also written the account of the Naiadaceæ in Engler and Prantl's "Die natürlichen Pflanzenfamilien" (1889), and still more recently a paper in the "Berichte der deutschen botanischen Gesellschaft" (1894). He clearly made out the relation of the floral parts and the anatomy and histology of the mature plant and fruit, as well as the general facts of germination; but he gives no account of the histology of the growing parts of the flowers. He also gives no account of the embryo, beyond a reference to the gross anatomy of the embryo in the ripe seed.

Schumann (1892) has also investigated the structure of *Naias*, but, like his predecessors, pays no attention to the minute structure of the floral parts. His results agree in the main with those of Magnus, but he does not agree with the latter in considering the envelope surrounding the ovule as a peculiar structure, but, in common with other botanists, regards it as a carpel, a view which Magnus vigorously opposes.

My own observations were based entirely upon *Naias flexilis* Willd., the only available species, and it will be necessary to examine critically other species before we can generalize as to results. It is true that all those so far examined agree closely in most of their details; but as in *N. flexilis* there is a considerable degree of variation in certain structures, especially in the embryo-sac, it is highly important that these should be compared with the corresponding ones in the other species.

The material used was collected in the Detroit river, but the species is of wide distribution in the United States and occurs in certain parts of California.

The genus *Naias* is of world-wide distribution, but owing to the great simplicity of the flowers and the variation in the habit of the same species, the limits of the species are very uncertain. There are probably about ten species known (Watson, 1880, p. 191; Morong, 1893, p. 60), of which four occur in the United States, two of these being found in California, (Watson, l. c.); i. e., *N. flexilis* and *N. major* (*N. marina* L.). They are all entirely submersed aquatics and remarkable for the extraordinary simplicity of the flowers, which consist respectively of a single carpel or stamen; and these are remarkably simple in structure and curiously similar both in their origin and early stages of development. It is generally considered that this extreme simplicity of structure is the result of the aquatic environment, but this is by no means certain, as the flowers cannot readily be considered as derived from any more perfect type, and the genus stands very much isolated.

Magnus (1870) has given a very complete and accurate account of the relation of the stem and leaves, and the position of the flowers. The slender stem has the leaves apparently in whorls of three, but a careful examination shows that in reality one of these three leaves is the basal leaf of a branch springing from the axil of one of the leaves. Except for this basal leaf on each branch, the leaves are in pairs, the lower of each pair always developing a branch from its axil, while the upper one is invariably sterile. A further examination shows that in place of the absent leaf at the base of the branch there is a flower, which may be either male or female in *N. flexilis*, but in *N. major*, which is diœcious, is always of the same kind on one plant. These flowers, as Magnus (l. c.) showed conclusively and as we shall see later, are morphologically the equivalents of axes, and the ovule and anther strictly terminal organs. Owing to this formation of a branch in the axil of one of each pair of leaves, the whole plant is bushy in form. Perhaps the most remarkable thing in regard to the flowers is their striking similarity, both in origin and structure, the male and female in the earlier stages being almost indistinguishable. The stamen is invested with envelopes which seem to correspond to the outer integuments of the ovule and possibly the carpel. A further discussion of these points, however, must be left for the present.

## I. THE GROWING-POINT OF THE STEM.

The relation of the leaves, stems, and flowers has been carefully worked out by Magnus and confirmed by Schumann. The writer has nothing to add to their conclusions; but in order to follow out the histological details, a brief review of the facts may be useful.

If the terminal bud is carefully dissected out, it will be found that the shoot terminates in a conical tip, which projects considerably above the lateral organs (fig. 1). The leaves arise in pairs, mostly on opposite sides of the stem (fig. 5). The lower one is larger, and its base extends around the stem in the form of a sheath; almost as soon as it is visible, there is formed, just above it, a protuberance (fig. 5, *k*), which a careful examination shows to be considerably extended laterally. Very early this outgrowth shows a cleft in the middle, by which it is divided into two nearly equal parts; of these, one becomes the beginning of the branch found in the axil of the older leaf, and the other the rudiment of a flower. At first it is impossible to distinguish between them, but soon they undergo further changes which render their recognition easy.

If a section is made, cutting through the centre of the apex, it presents the appearance shown in fig. 5. The primary tissue-systems are clearly recognizable and show the arrangement typical of most angiospermous plants. There is, as usual, a well defined epidermis, all of whose cells are for some time capable of division, but the divisions are always radial, and this epidermis continues without break over the apex, and over the surface of the young appendicular organs. Below the epidermis is the periblem, also composed for the most part of a single layer of cells in the younger parts, but of course later undergoing periclinal divisions. The plerome is well marked, and in longitudinal section shows usually two rows of cells. A single large cell (fig. 5, *x*), which is sometimes conspicuous, may perhaps be the single initial cell for the plerome, but its position is such as to make it also possible that it belongs to the periblem, and that there are several initial cells for the plerome.

In regard to the form of the stem-apex, *N. flexilis* resembles more nearly *N. graminea*, to judge from Schumann's figure (fig. 1), than it does *N. major* (Magnus, 1870, Pl. IV, figs. 6–11), where the apex is shorter and thicker than in any of the other species. The apex of the stem is seldom perfectly straight, and the first indication of the formation of the lateral appendages is the appearance of two slightly projecting ridges, one immediately above the other and placed upon the convex side of the apical cone (figs. 3, 5, *k*, *l*). The lower one of these is the leaf and the upper the structure (primordium) which subsequently gives rise to a lateral branch and a flower. A little later there is found on the opposite side of the apical cone and a little higher up than the other leaf, another projecting ridge, which does not, however, show any structures above it. This is the second leaf of the pair (fig. 5, $l^2$). The tissues of the appendages show the same arrangement as those of the stem-apex and are continuous with them.

The tissues of the mature stem are very simple, but their origin is readily traceable to the primary tissues of the apex. As in all aquatics, large air-channels are developed, arising here between the two outer layers of the cortical cells. In the specimen of *N. flexilis* figured (fig. 6), there were six of these intercellular spaces (*i*), and the general structure is much the same as in *N. minor* (Magnus, 1870, Pl. VII, fig. 4). *N. major* (Magnus, 1870, Pl. VII, fig. 2) has a more massive stem, a larger number of air-spaces, and a thicker cortex. There is in all cases a single axial, vascular bundle, with a well defined endodermis, showing, when mature, the characteristic radial foldings of the walls, and derived as usual from the innermost layer of the periblem.

The intercellular spaces are separated by a single layer of cells, and the general appearance of the section is much like that of such aquatic Pteridophytes as *Marsilia* or *Azolla*. Like these, the bundle is typically concentric. Magnus (1889, p. 215) states, and his statement has not been contradicted, that there is no tracheary tissue present. This is incorrect, at least for *N. flexilis*. In longitudinal sections of the younger parts of the stem, spiral or annular tracheids are always found, forming a single line in the axis of the bundle. The thickenings on the walls are formed at an early period, and with the rapid growth of the stem in the lower internodes, these primary tracheids are pulled apart and destroyed, leaving the central canal, which Magnus figures. It may be noted that Caspary (1858, p. 515) noted traces of these tracheæ in this same species, at the base of the funiculus, but apparently overlooked them in the other parts of the plant. It is evident from his account, however, that his investigations were not very extensive, and it is by no means unlikely that further investigation, using microtome-sections of the younger parts of the stem, will reveal the presence of tracheids with normal thickenings, in the other species as well as in *N. flexilis*. In common with other submersed aquatics, *Naias* has the epidermal cells containing chlorophyll, and not noticeably different in form or contents from the outer cells of the cortex.

## II. THE LEAVES.

The structure and arrangement of the leaves is very similar in all species of *Naias* yet investigated. The base of the leaf is expanded and forms a sheath surrounding the stem more or less completely. In the case of the sterile leaves, i. e., those which develop no axillary products, the base of the leaf envelops the stem completely and one edge overlaps the other, much as is found in the case of the cotyledon (fig. 80). The marginal cells of the leaf are extended into the brown teeth, which gives the leaves a distinctly serrate outline. Cross-sections of the leaf show a structure similar to, but simpler than that of the stem. In *N. flexilis*, except in the middle, the leaf is composed of but two layers of cells. The center is traversed by a vascular bundle, much like that of the stem, but without a definite endodermis. In the younger stages, a single line of tracheids can be seen penetrating into the base of the leaf, but no trace of these is visible in sections of the fully developed leaf. The bundle is surrounded by a layer of large cells, which abut immediately upon the small intercellular space on either side of the bundle. *Naias major* (Magnus, 1870, p. 49) differs markedly from all the other species in having a well marked epidermis consisting of small cells. This is correlated with the thicker cortex of the stem[1]. Between the base of each leaf and the stem are two scale-like structures, the "squamulæ intravaginales," structures found very generally throughout the Naiadaceæ and Potamogetonaceæ.

## III. THE ROOTS.

The primary root of the *Naias flexilis* is remarkable for the absence of a root-cap, a fact which has apparently been hitherto overlooked. Unfortunately my material of the mature plants did not include the roots, and I am unable to say whether this condition is also found in the later roots, nor have I been able to find any reference to the subject elsewhere. As to the position of the roots in the fully developed plant, the writer cannot speak from his own observations, and the account given by Magnus (1870, p. 16) is not entirely clear. To judge from his figures, however, it would appear that the roots are produced in regular succession, one to each of the lower nodes of the stem, arising between the two leaves of the node on the side toward the leaf at the base of the branch.

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[1] For further details of the structure of the leaves, the reader is referred to Magnus' monograph.

## IV. THE FLOWERS.

The flowers of *Naias* represent the simplest form which an angiospermous flower can assume, consisting simply of a single carpel with but one ovule, or of a single stamen, which in most species has but one pollen cavity. In origin and in their earlier phases of development, ovule and stamen present very marked similarity, and this is heightened by the development about the stamen of structures corresponding to the integument of the ovule, and of an envelope which imitates very closely the carpellary covering of the ovule; this even extending to the formation of similar teeth at the apex. The resemblance of both to the sporangia of certain Pteridophytes, especially *Azolla*, where the macrosporangium has a similar investment, is also noteworthy.

As we have seen, the rudiment of the flower is formed by the equal division of the primordium, which is formed above the lower of each pair of leaves. At first these are not distinguishable, but very soon one of them becomes somewhat larger than the other (fig. 11, *f*), and this, which is the young flower, soon develops about it a ring-shaped wall—the carpel or its equivalent—and thus is readily distinguishable from the other protuberance, which is also more pointed and becomes the apex of the lateral shoot. It is thus plain that the origin of the ovule or anther, as the case may be, is strictly terminal; i. e., that the flower and the lateral branch are due to the dichotomy of a common primordium and therefore are of equal morphological value. The male and female flowers are scarcely distinguishable at first, as the envelope about each is entirely similar; but as a rule the young ovule is somewhat more slender than the anther. The question of the homologies of the envelopes of the flowers will be better understood after considering the development of the latter.

1. THE MALE FLOWER.—Shortly after the separation of the primordium into the rudiments of the lateral branch and flower, the latter grows much more rapidly, and its real nature becomes evident. It begins to broaden at the base

(fig. 8), and this enlargement quickly assumes the form of a ridge running round it and growing up about the apex in the form of a cup-shaped envelope. A longitudinal section of the young male flower at this stage shows a structure very similar, as might be expected, to that of a vegetative shoot. A definite epidermis covers the apex, and the inner tissues show a separation into plerome and periblem, although not quite so definite as in the vegetative apex. There is next to be seen a second envelope growing up, separated from the first by a short interval and remaining closely applied to the body of the stamen, which latter is formed from the whole of the terminal part of the flower; i. e., the apex of the floral shoot is transformed directly into the anther. The resemblance to the young ovule invested with its single integument is very striking, and it is difficult to see why this inner envelope of the stamen should not be considered to be the homologue of an ovular integument. At this stage there can usually be made out a pretty definite central row of cells (fig. 9), corresponding to the plerome of the vegetative shoot, and from which, alone, the sporogenous tissue arises. The outer envelope grows more rapidly than the inner one and soon extends far beyond the apex of the anther. It consists throughout of two layers of cells. Whether this envelope is to be regarded as a perianth, or whether it is the homologue of the carpel, or finally whether it is to be considered merely as a bract, it is difficult to say. Its absolute similarity in origin to the outer envelope of the female flower is perfectly obvious, and Magnus (1870, p. 38) tries to solve the question by denying that this envelope in the female flower is really of carpellary nature, but states that it is rather of the nature of a bract or rudimentary perianth, comparable, perhaps, to the envelope about the pistillate flower of *Zannichellia*.

At the time when the archesporium is first recognizable, the anther (fig. 12) shows an epidermis, below which are two rows of cells surrounding the plerome cylinder. It is the upper cells of the latter which constitute the archesporium, but its exact limits are not easily determined. It is pretty certain, however, that its origin is not traceable to a single cell. As the anther grows, the archesporial cells rapidly divide in all directions and become distinguished by their denser contents and larger nuclei (fig. 13); but even in the later stages the boundary between the sporogenous cells and those lying outside is not always perfectly clear. In general, however, the two layers of cells lying within the epidermis do not divide any further by periclinal walls, and the inner one may be considered as a tapetum. The outer cells later become much compressed by the growth of the sporogenous tissue, and the inner layer almost absorbed before the final division of the spore-mother-cells. Before the spore-mother-cells separate, the inner envelope, or integument, has grown up beyond the apex of the anther, and the cells of the upper part become enlarged, so that two thickened lobes are formed, the whole, in section, closely resembling the micropyle of an ovule (figs. 14, 15). The flower has a short, thick stalk, and in the center is a vascular bundle, which, like the other parts of the plant, shows in its earlier stages a single row of short annular or spiral tracheids, which are later destroyed by the rapid elongation of the pedicel.

(*a*) *Development of the Pollen.*—The spore-mother-cells, previous to their separation (fig. 15), show the usual dense, granular contents. The nucleus is of moderate size, with a distinct but not specially large nucleolus. The individual cells are decidedly elongated, and even after they separate retain this form (figs. 17–21). Just before the first nuclear division takes place, the nucleus appears larger than in the cells which have not yet separated, and the protoplasm presents a more or less definitely vacuolar appearance. Probably the centrospheres are always present, but it must be admitted that the observations made were by no means conclusive. Owing to the granular nature of the cytoplasm and the difficulty in differentiating these very elusive bodies, the writer does not feel in a position to speak positively about the matter, and must pass over the behavior of these structures during the process of nuclear division.

The divisions of the spore-mother-cell are successive, and the resulting pollen-spores of the bilateral type common to most Monocotyledons. The successive stages in the division of the spores is shown in figs. 17–22.

It follows the usual form, and there were no remarkable variations from the common type of nuclear division. The number of nuclear segments could not be determined positively, but it is not very large, probably 8–12. During the earlier phases of division the nuclear spindle was distinct and relatively large, the nuclear segments not occupying the whole of the equatorial diameter. The formation of the connecting threads, the cell-plate, and finally the cellulose division wall, agree with other Monocotyledons, and the subsequent divisions of the cells, resulting in the tetrads of spores (fig. 22), show nothing peculiar. Unlike most Spermaphytes, both spore-mother-cells and spores have thin walls; this is probably simply an accompaniment of the aquatic habit, but it is interesting, as the spore-mother-cells in this respect are more like those of the Pteridophytes than those of the typical Spermaphytes. After the division is complete, the young spores separate and round themselves off, but do not develop the cuticularized exospore found in most plants. This is no doubt simply the result of their submersed condition, for, as they remain permanently under water, such a condition would naturally be expected. The young spore at this stage is a globular thin-walled cell, with nearly clear contents, and contains a single, large nucleus. It soon, however, divides into two cells of very unequal size, a large vegetative cell and a small antheridial one. These are separated by a distinct membrane (fig. 23), and are also distinguished by the very unequal size and different appearance of the nucleus. That of the vegetative cell is large, with a distinct nucleolus, but comparatively poor in chromatin. The nucleus of the generative or antheridial cell has a very inconspicuous nucleolus, but stains deeply with ordinary staining agents. After the division of the pollen-spore it rapidly grows, becoming much elongated, and before it is ripe there is a division of the generative cell into two. The terminate in dark brown teeth, like those upon the envelope of the staminate flower (fig. 46); the other two, which alternate with the tooth-bearing lobes, are more or less distinctly papillate, and may be called the stigmatic lobes (fig. 45). A narrow canal traverses the style, and surrounding the place where it enters the ovary, there are a number of projecting papillæ, much like those found in certain Aroids. A similar group of papillæ is found at the base of the funiculus, close to the micropyle (fig. 47). The ovule arises from the base of the ovary and is bent on itself, so that the micropyle is close to the insertion of the funiculus. The whole structure of the pistil corresponds to that of the typical Angiosperms, and it is difficult to see any valid reason for accepting Magnus' view that this envelope is not of the nature of a carpel.

The origin of the female flower is identical with that of the staminate one. Like the latter, the floral rudiment is formed by the dichotomy of a primordium, the other half of which develops into a branch; and as was the case with the anther, the ovule is the transformed apex of the floral shoot. In their earliest phases, the two sorts of flowers are scarcely distinguishable; but while still very young, the female flower can be recognized by the greater development of the envelope and the more slender form of the apex of the shoot. The structure of the young flower, seen in longitudinal section (fig. 34), is very much like that of the male flower; but the young ovule is distinctly narrower, and the outer envelope (carpel) has already reached beyond its apex before any trace of the ovular integuments is to be seen. The arrangment of the tissues is much the same as in the young anther, but the plerome consists of but a single row of cells, separated from the epidermis by a single-layered periblem (fig. 34). A noticeable difference in the two is the origin of the archesporium. This, instead of arising from the plerome, as in the anther, can be traced to a single hypodermal cell, which, however, is apparently continuous with the single axial row of plerome cells. This archesporial cell is the shaded cell in fig. 34.

The first integument becomes evident about the same time that the primary archesporial cell undergoes its first division. The basal part of the ovule enlarges and the integument appears in the form of a ring, in the ordinary way, and grows up about the upper part of the ovule, which becomes the nucellus (figs. 35, 36). The growth is stronger on one side, almost from the first, the nucellus begins to bend over, and the anatropous position of the mature ovule is thus indicated. The first integument, like the corresponding structure in the stamen, is two cells thick and closely resembles it in nearly every particular. It closes over the top of the ovule, leaving, however, the narrow micropyle open. The second integument, as usual, is developed just below the first one (figs. 38, 39), but is almost entirely suppressed on the side in contact with the funiculus (fig. 47). Even up to a late period the second integument remains behind the inner one, but finally extends to about the same level.

The funiculus has an axial vascular bundle which develops a single line of tracheids with spiral or annular thickenings, which, like those in other parts of the plant, are ultimately almost completely obliterated. From its basal part, close to the micropyle, a bunch of short secretory cells is found, probably concerned with the directing of the pollen-tube into the micropyle.

The further development of the archesporium shows considerable variation, but corresponds in its essential details with the typical form in most other Angiosperms. The primary archesporial cell very early divides by a transverse wall into an outer tapetal cell, and a larger inner one (fig. 36), and the former next divides into two by a second transverse wall (fig. 35). Usually the tapetal cell undergoes no further development, at least until a much later period. In one exceptional case observed (fig. 38), where the archesporium was divided into five cells, it was not possible to determine positively whether the third and fourth cells, which were obviously sister cells, had been derived from the division of the tapetum or from the inner of the two primary this was the only instance of the kind found, it is not possible to say what the origin of this tissue was; but it probably may be considered as mainly due to the development of the endosperm. So far as I know, such a development of the prothallial tissue in Angiosperms, except as a result of fertilization, has not been recorded.

The general development of the carpel has been treated fully by Magnus, but he did not study some of the minute details herewith given. In *Naias flexilis* the carpel rapidly grows up beyond the enclosed ovule, and just above this point there is a marked thickening of the walls (fig. 37), so that the pistil is closed above except for a narrow canal in the middle, which communicates with the cavity of the ovary. Very early, too, the margin of the carpel shows unequal growth, resulting in the formation of four lobes (fig. 40), of which two are decidedly longer than the others (indeed, in the case figured, one of the smaller lobes is scarcely visible). The two longer lobes finally have the terminal cell transformed into a thick-walled brown spine (fig. 46). The two shorter lobes between the spiny ones are the stigmatic lobes; these have the terminal cells more or less papillate. In *N. major* there are three papillate lobes, and in *N. minor* and most other species, two; but none of these species has the spiny lobes (Magnus, 1870, p. 20, Pl. II). Two Brazilian species, according to Magnus (l. c., p. 21) have the same structure as *N. flexilis*. There are also several Mexican species which sometimes show a similar structure, but they are extremely variable, while in *N. flexilis* this structure is usually very constant.

Finally, there must be noted the occurrence of a second envelope in several species (Magnus, 1870, p. 22, Pl. III, figs. 1–3), among which may be mentioned *N. ancistrocarpa*. Here the outer envelope bears several spiny teeth, while the inner one (carpel) bears two stigmatic lobes. This outer envelope is perhaps to be considered as a floral envelope and the possible homologue of that surrounding the stamen. The case of *N. flexilis* suggests that the two envelopes are of the same nature and that this species is intermediate between those like *N. major*, where there are only stigmatic lobes found, and those like *N. ancistrocarpa*, where two distinct envelopes, perianth (?), and carpel are developed.

The wall of the ovary is composed for the most part of but two layers of cells (fig. 47); but the walls of the style, especially at the base, are thicker. The style in our species is longer than in most others and is traversed by a very evident canal (fig. 47). Schumann (1892, p. 183) failed to see this, but it was accurately described by Magnus. While still quite young the cells at the base of the canal, lining the ovarian cavity, enlarge and soon project into the cavity as conspicuous papillæ (figs. 48, 49). The contents of these cells are very dense, and the nuclei become very large and conspicuous. It is evident that they are secretory cells, and the presence of a structureless substance, often quite filling the cavity and staining strongly with Bismarck brown, suggests that the secretion is of a mucilaginous nature and is in all probability concerned with the direction of the growth of the pollen-tube. The bunch of similar papillæ at the base of the funiculus has already been referred to. The cells of the style next the canal are very narrow, but the outer ones are much broader, and those at the base of the style elongated radially, so that there is a distinct enlargement of the pistil just above the ovary. In the cells of the style were noticed numbers of crystals of calcium oxalate, mostly octahedral in form.

## V. POLLINATION.

The pollen-grains probably are carried to the stigma by the movements of the water, although in the form of *Naias flexilis* studied by the writer, the position of the open anther would allow of their falling spontaneously upon any female flowers that might be situated below them. Jönsson (Magnus, 1889, p. 216) concludes that this is regularly the case, the pollen being heavier than the water and striking upon the female flowers which are placed lower down. Magnus' objection, that the male flowers stand upright and so prevent the pollen-spores falling out spontaneously, will not hold for *N. flexilis*, nor has the writer observed in this species the pollen germinating within the cavity of the open anther as Magnus (l. c.) found to be the case.

Germinating spores were found in abundance upon the stigmas of the mature flower. The pollen-grains were held between the stigmatic lobes and in some cases seemed to adhere to the style, possibly by a secretion of the stigmatic cells. The germination is probably entirely at the expense of the spore contents and no nutriment is apparently received from the stigmatic cells. The tube quite as often grows down on the outside of the style as between its lobes. Some of the pollen-tubes, however, penetrate into the canal of the style and make their way into the ovarian cavity. After reaching this, it is extremely likely that they are nourished by the secretion of the papillæ at the lower opening of the canal, which seems to fill the cavity of the ovary. The exact course of the tubes was not traced, as they are not easily seen in sections; but probably the course follows the inner wall of the ovary until the group of papillæ at the opening of the micropyle directs the growth of the tube into the micropyle itself. The end of the pollen-tube, where it was found on the outside of the style (figs. 32, 33), was usually slightly swollen and contained dense, finely granular protoplasm, in which, in favorable cases, could be seen the two, small, generative nuclei. In none of those examined could the vegetative nucleus be seen with any certainty. In the germinating spores the outline of the pollen-spore was retained, but all the granular contents had passed into the tube and mostly disappeared as the tube lengthened.

## VI. FERTILIZATION.

The penetration of the pollen-tube into the embryo-sac was seen in several instances, but the nuclear elements are too small to make this a specially favorable subject for the study of the phenomena of fertilization and no very detailed investigation was made.

At the time that the pollen-tube enters the embryo-sac, the apical cells of the nucellus enlarge and their walls stain more strongly than before, as if there had been a change in their composition. Probably they become somewhat mucilaginous and thus are more easily forced apart by the growing pollen-tube. The latter, after it has entered the micropyle, pushes down between the cells of the nucellus (figs. 57, 58), forcing them apart and finally penetrating the wall of the embryo-sac. After it has entered, the end enlarges, sometimes very much (fig. 58), and this seems to be at the expense of the contents of the part of the tube lying outside of the embryo-sac, which in the specimens seen was much collapsed. The pollen-tube was not nearly so conspicuous as Schaffner figures it for *Alisma*, but the further history corresponds closely with his account. As in other cases that have been described, one of the synergidæ appears to be regularly destroyed by the growth of the pollen-tube close to it, and collapses completely, while the other remains intact for some time longer. For demonstrating the presence of the pollen-tube within the embryo-sac, the anilin-safranin method recommended by Schaffner (1896, p. 123) was found to give good results, although here, too, I failed to see the centrospheres which he figures and describes in *Alisma*. One or both of the generative nuclei could be seen and, in some cases at least, had changed form, becoming somewhat elongated. The actual penetration of the generative nucleus into the egg and its fusion with the egg-nucleus, were not seen; but there is no reason to doubt that it takes place in the usual way.

## VII. THE EMBRYO.

The embryogeny of *N. major* has been worked out by Hofmeister[1], but his paper was not accessible to me, so that I cannot say how his results compare with my own on *N. flexilis*, which are here given. Some important differences were noted between this species, however, and the generally accepted account of the early divisions in the monocotydenous embryo, which tend to verify the recent account given by Schaffner for *Alisma*, and to indicate the necessity for a further revision of the older work on the embryogeny of other Angiosperms.

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[1] Hofmeister—"Neue Beiträge zur Kenntniss der Embryobildung der Phanerogamen." Leipzig, 1861.

After fertilization is effected, the egg becomes invested with a cellulose membrane and elongates considerably before dividing. It is in contact, usually, with the wall of the embryo-sac, except at the apex. The nucleus at this stage (fig. 60) is large and very conspicuous, with large nucleolus and abundant chromatin. The cytoplasm is granular, especially at the apex, where the nucleus is placed. At this stage one of the synergidæ is still unchanged, but the other can no longer be made out, nor is the pollen-tube any longer visible.

The first division wall, as usual, is transverse, dividing the egg into a basal, or "suspensor," and a terminal, or "embryo," cell. The basal cell, which is applied to the wall of the embryo-sac, undergoes no further division, and all the subsequent growth of the embryo is due entirely to the divisions of the terminal cell. Hanstein (Sachs' Text-book of Botany, 1882, p. 589) states that in *Alisma* the terminal cell only produces the cotyledon, while the basal, or suspensor cell, undergoes further divisions by transverse walls, resulting in the formation of other parts of the embryo. Famintzin, to judge from the review of his paper in Just's Jahresbericht (Jahrg., VII, heft 1, p. 90), agrees in the main with Hanstein. According to his account, the first three divisions are transverse and occur in regular basipetal order, and these result at once in the establishment of the initials for cotyledon, stem, and root. The early stages of the embryo of *Alisma* have been investigated recently by Schaffner (1896, pp. 129, 130), and he states that the conclusions of Hanstein and Famintzin are either incorrect, or that there is remarkable variation in *Alisma*. According to his account, the basal cell undergoes no division, agreeing with my observations in *Naias*, and the next divisions are acropetal, the terminal cell dividing twice. He says that he has verified this repeatedly, having followed the stages of nuclear division, so that there was no doubt about the accuracy of his conclusions. Inasmuch as my own investigation of *Zannichellia* also shows that the basal cell remains permanently undivided, it seems quite probable that this is regularly the case and that this cell never takes any further part in the formation of embryo. Further investigations on the point are very much to be desired.

The second division takes place in *Naias flexilis* after the terminal cell has elongated, and results in the formation of two cells of unequal size. Whether the next division is due to a second segmentation of the terminal cell, as Schaffner describes for *Alisma*, or by division of the middle cell, could not be positively determined; but it certainly was not formed by a second division of the basal cell. The latter almost as soon as it is formed begins to enlarge, and its nucleus also increases very much in size, finally reaching enormous dimensions, but never showing any indication of division[1]. This, as Schaffner has shown, is also true for *Alisma;* and Scott (1894, pp. 187, 188) in a recent work has reached the same conclusion, although it is not clear from his statement whether he considers the middle of the three cells of the young embryo as arising from the division of the upper or lower of the two primary cells. Following these transverse walls in the young embryo, there is next formed a vertical wall in the terminal cell, which latter develops into the single terminal cotyledon of the older embryo. This is next followed by a similar wall in the cell below it, and about the same time, by a transverse wall in the cell next the enlarged basal cell. At this stage the embryo consists (fig. 64) of the very much enlarged basal cell, followed by two short secondary suspensor cells, and terminated by a nearly globular body composed of four cells arranged like the quadrants of a sphere. Each of these sphere-quadrants next divides by octant walls, and from the upper four arises the cotyledon; from the lower ones, the middle part of the embryo and stem-apex. There is now formed in each octant cell a periclinal wall, separating it into an inner and outer one, the latter constituting the dermatogen of the upper part of the embryo (fig. 65).

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[1] This appears to be much less marked in *N. major* (see Magnus, 1870, p. 31).

While these changes have been going on in the upper part of the embryo, the cell next below has enlarged laterally, and the one below this divided again. In the former there are then formed quadrant walls, and each of the quadrant cells next separates into a peripheral, or epidermal cell, and an inner one, exactly as was the case in the two upper divisions.

Up to this point all the secondary divisions, except the periclinal ones in the upper section of the embryo, have been vertical, and the limits of the primary segments are still very evident (fig. 66). The first transverse divisions appear in the middle segment, and this determines the separation of the stem from the root, the bulk of both of these organs being derived from this segment of the embryo. If the accounts of Hanstein and Famintzin are correct, *Alisma* differs very essentially from *Naias*, in that the root of the former is not the product of the middle cell, but of the one next the suspensor, and is derived from it by a secondary division. As the term hypophysis, used by Hanstein for this basal segment, implies a structure not belonging strictly to the embryo itself, but to the suspensor, it would seem best to discard this term, as Schaffner has shown that in *Alisma*, also, the primary suspensor cell undergoes no further divisions and all the parts of the embryo are derivatives of the primary embryo cell. In both Hanstein's and Famintzin's figures, transverse walls are shown in the terminal segment before any periclinal walls appear, but it is quite possible that we really have the same state of things as in *Naias*, and that the two lower cells of the four terminal sphere-quadrants really belong to the second of the primary segments of the embryo and not to the terminal one. However, as the cotyledon of *Alisma* is larger at this stage than that of *Naias*, and the whole embryo longer, it is quite possible that the four terminal quadrants may arise as stated by Hanstein and Famintzin, but further investigations are needed to settle this.

A study of the older embryos of *Naias* shows that the great bulk of the embryo is derived from the first two segments. The third one, as we have already seen, forms a series of transverse walls; and of the cells thus formed, the two upper ones divide by a series of longitudinal walls, but no secondary transverse walls are formed, at least for some time, so that they form single layers of cells, easily recognizable in exact median sections of the older embryos. The lower of the two has only a limited development and forms a small group of cells continuous with the epidermis of the rest of the embryo (fig. 70). The segment above it, like the terminal ones, has first two intersecting median walls, and next, by periclinal walls, the epidermis is separated.

The differentation of the primary tissue-systems is brought about very early and is especially evident in the middle region of the embryo (figs. 68, 70). The dermatogen, as we have seen, is determined by the first periclinal walls in the upper segments (fig. 65), and this is followed later by the somewhat similar division in the next lower one. The separation of plerome and periblem is determined in the upper segments by the subsequent divisions, which are longitudinal and divide each of these segments into a group of four central cells (two when seen in logitudinal section) and a single layer of cells between them and the epidermis—the periblem. The formation of these primary tissues is very regular in the central segment, from which the stem and root are formed, but in the cotyledon they are not quite so clearly defined. Famintzin states that in *Alisma* there is at first but a single plerome cell in each segment, but Hanstein's figures show an arrangement very similar to that in *Naias*, and as Famintzin studied this from optical sections, it is quite probable that he was mistaken. Even from a study of his own figures, it is difficult to understand how he can have reached this conclusion. In the basal segment of the embryo of *Naias* there is no formation of a plerome, but all the inner cells form the initial cells for the periblem of the root and are continuous with the periblem of the middle segment. Finally, the segment below this is simply a continuation of the epidermis of the rest of the embryo, which thus extends without interruption completely around it. About as soon as the tissue-systems are clearly defined, there begins the external differentiation of the embryo into the primary organs of the young plant.

## VIII. THE COTYLEDON.

The cotyledon of *Naias*, as in other typical Monocotyledons, is strictly terminal and is the product of the whole of the terminal segment of the embryo. There is early a marked enlargement in the middle region of the embryo (figs. 69, 70), corresponding to the stem-segment, while the cotyledonary portion, although elongating, does not increase so rapidly in diameter. This enlargement of the stem-segment is largely on one side and results in the formation of a prominence at this point (figs. 70, 71, *st*)—the apex of the stem of the young plant. It is evident that this is here strictly lateral in origin. By the growth of the stem-apex, which is quite active from the first, the cotyledon is pushed somewhat to one side. The growth of the cotyledon, which is at first terminal and due largely to the growth of the tissues at the apex, is soon replaced by the formation of a zone of meristem at the base, which not only causes the subsequent growth in length, but by the active multiplication of the cells laterally forms a sheath-like stipular growth, surrounding the base of the cotyledon (fig. 69) and finally completely concealing the stem-apex, which comes to lie in a cavity completely enclosed by the overlapping edges of the leaf-base (figs. 72, 73). In median sections of the young cotyledon (fig. 70, *b*), the separation of the tissue-systems is evident, but the plerome is never so well developed as in the stem and root, and this corresponds with the slight development of the vascular bundle in the mature cotyledon. The fully grown cotyledon is about half the length of the whole embryo (fig. 73).

## IX. THE STEM.

The origin of the stem is, as we have seen, lateral, and it can be readily traced to the upper half of the middle segment of the young embryo. The projection of the apex is brought about by an acceleration of the growth in the dermatogen and plerome at one point of the segment, which soon results in the development of an evident bluntly conical protuberance, which grows rapidly and assumes a more pointed form. A longitudinal section of the embryo at this time (fig. 70, *a*) shows that the plerome cylinders of the stem, leaf, and root are continuous, forming a single axial strand; but at the point where the stem-apex is forming there is an enlargement of the plerome, which is beginning to form a branch going into the stem. Very soon after this, the stem-apex shows the same arrangement of tissues as is found in the fully developed embryo.

## X. THE ROOT.

The primary root of the *Naias* differs in several important points from that of the other Monocotyledons that have been described. In the first place, the bulk of the root, at least the whole of the plerome and part of the periblem and epidermis, are parts of the same segment of the embryo as the stem, while the plerome initials and terminal epidermis alone are formed from the lowest of the primary embryonic segments. Another very important difference is the complete absence of a root-cap. In none of the specimens examined was there the slightest trace of this structure, unless we can regard the cells at the apex of the root, which are continuous with the epidermis of the rest of the embryo, as such. Unfortunately Hofmeister's paper, where the embryogeny of *Naias major* is described, was not accessible, and so we cannot now make a comparison with that species; but no mention of the absence of a root-cap in *Naias major* is made in any of the references to Hofmeister's paper examined by me. The separation of the root from the stem does not occur until after the differentiation of the tissue-systems and similar ones are developed later in the axils of all the other leaves. The stem-apex at this time projects strongly and shows the same arrangement of cells as in the mature plant (fig. 74).

All the cells of the embryo contain starch in large quantities, and the nuclei are very distinct and rich in chromatin. The walls of the superficial cells are rather thick, and, perhaps, cuticularized, and it is quite possible that the embryo is mainly nourished through the enormously enlarged suspensor cell, where the thick, granular cytoplasm and large nucleus suggest that it is actively concerned in the elaboration of food for the growth of the embryo.

## XI. THE ENDOSPERM.

The actual fusion of the two polar nuclei to form the primary endosperm nucleus was not seen, although in one or two instances they were found in close contact (fig. 50), apparently in process of fusion; and in only a few instances was a single endosperm nucleus observed. So generally were the polar nuclei separate, that the possibility of there being no fusion suggested itself. However, this latter is merely a suggestion which was not proved. A peculiarity noted, which was also observed in *Zannichellia*, was the presence of a single large nucleus close to the antipodals, which was conspicuous at an early period and behaved much like the nucleus of the suspensor. Whether this was the lower polar nucleus or one of the two endosperm nuclei resulting from the first division of the primary endosperm nucleus, could not be determined. Whichever is the case, it never divides, and all the endosperm nuclei arise from the division of the other primary endosperm (or polar?) nucleus. The development of the endosperm is limited, there being usually no trace of cell formation. The endosperm nuclei are distinct, with a well marked nucleolus, and are embedded in the granular cytoplasm lining the wall of the embryo-sac, and especially in that immediately about the young embryo (fig. 64, *k*). In the later stages they present quite a different appearance, having a less sharply defined contour, and they are much more granular. These later stages also often show more than one nucleolus, each being surrounded by a clear area. Some of these nuclei have the appearance of being formed by the fusion of two or three, but this could not be determined positively (fig. 59, *b*).

The lower nucleus (fig. 59, *a*) finally reaches an extraordinary size and becomes a very conspicuous feature of the embryo-sac. It lies close to the wall of the embryo-sac, above the antipodal cells, and is surrounded by granular cytoplasm. It has a very large nucleolus, which shows a distinctly vacuolar structure. The chromosomes are remarkably distinct and form thick sinuous threads, staining readily, and occasionally with still more deeply stained granules embedded in them. The close resemblance between this nucleus and that of the suspensor is noteworthy.

The development of the fruit was not followed, as Magnus (1870, p. 41) has given a full account of this in his monograph of the genus. For a time there is a growth of the outer cells of the nucellus, keeping pace with the developing embryo-sac; but, according to Magnus, the whole of the tissue of the nucellus and inner integument is destroyed by the growing embryo, and only the outer integument develops further to form the somewhat complicated seed-coat. The carpel itself remains membranaceous and forms simply a thin investment for the seed.

## B.—Zannichellia.

The genus *Zannichellia* contains but one species, *Z. palustris*, a plant of almost world-wide distribution and not uncommon in California. While several species have been described, the more recent students of the genus have reduced them all to a single one (Ascherson, 1889, p. 213). Like *Naias*, the plant is an entirely submersed aquatic, growing either in stagnant or running water. While usually a fresh-water plant, it is also said to grow in brackish water. In general appearance the plant recalls *Naias*, but has longer and more slender leaves and stems, and on closer examination is found to resemble more some of the slender species of *Potamogeton*.

The flowering shoots arise from a creeping rhizome, and each node develops two slender, unbranched roots, which finally penetrate the mud and hold the plant firmly in position. The slender stems are abundantly branching, at least in the specimens examined by the writer. At each node there is an apparent whorl of three leaves, as in *Naias*, below which is a delicate, membranous, cylindrical sheath, which completely envelopes these in their younger stages; and an entirely similar sheath forms a bell-shaped involucre about the pistillate flower, or, more correctly, inflorescence. The male flower here, as in *Naias*, is reduced to a single stamen and is borne close to the female inflorescence at each node. Of the three grass-like leaves at each node, the two lower are opposite and have a membranous, closed, stipular sheath; the third leaf is above these and the sheath is either wanting or is incomplete. The plants from which the following account was made were collected at Stanford University, in a ditch in which the water is usually running swiftly. Most of the material was collected in the late winter and early spring, but during November and December of 1896 the plant was found with fruit and a few flowers. Ordinarily, however, the plant has been observed only in the early spring months.

There is much disagreement as to the systematic position of *Zannichellia*, as we have already intimated. In our American manuals the plant, in common with several other genera, is placed in the family, Naiadaceæ (Morong, 1893; Britton & Brown, 1896, p. 79). In Engler & Prantl's "Natürliche Pflanzenfamilien" the family Naiadaceæ is made to include only the single genus *Naias*, and *Zannichellia* is placed in the Potamogetonaceæ, but forming a special subfamily Zannichelliæ. Schumann (1892), who has made the most recent study of the genus, considers it to be sufficiently distinct from the other Potamogetonaceæ to rank as the type of a separate family, Zannichelliaceæ, in which is also included the genus *Althenia*, and this view is probably borne out by a study of the facts of structure and development.

In his careful study of the morphology of *Zannichellia*, Schumann has given a review of the literature bearing upon the subject and refers to the early work of Irmisch, who was the first to make a detailed account of this plant. Eichler, in his "Blüthendiagrammen" (1875, p. 1), also treats briefly of the morphology of this plant; and most recently of all, there are some brief references to the structure of the female flower in a paper by Magnus (1894, pp. 222, 223) called out by Schumann's work. Beyond those references the writer is not aware of any other accounts of the plant, beyond the ordinary ones in the descriptive manuals. Even in the work of Schumann, which is much the most complete so far as the flowers are concerned, no attention is given to the histology, which has apparently never been examined at all.

In studying the development of the tissues of the young vegetative organs and flowers, the same methods were used as in *Naias*, and the results given were mainly obtained from series of microtome-sections.

## I. GENERAL MORPHOLOGY.

Schumann (1892, p. 155) has made a very careful study of the arrangement of the stem, leaves, and flowers, and has shown that the only way to understand clearly their real relationship is to study the history of their development. While he succeeded in correcting some of the errors of the earlier observers, he himself failed to reach a clear understanding of the relation of the flowers to the main axis of the plant, from failure to study sections of the youngest stages. He showed conclusively that the anther was a truly terminal structure, as in *Naias*, but the group of carpels, which, in common with Magnus, he is inclined to consider as a single flower, he concludes to be the transformed apex of the main axis, a view which, as we shall see, is not borne out by a study of the youngest stages.

The general study of the apex of the stem and the origin of the lateral members is very much as in *Naias*. The stem-apex shows a conical form, and from it are produced the leaves in a quite similar manner. It differs from *Naias* in the formation of the sheath (fig. 81, *sh*) below each node. As in *Naias*, the lower of the two leaves alone develops axillary structures, the upper one being sterile. The products developed from the axil of the lower leaf of the pair are the stamen and a lateral branch. Schumann considers that the apex of the main axis develops into the female inflorescence and that the continuation of the axis, which is a sympodium, is due to the development of a lateral shoot in the axil of the second leaf. In reality the second leaf does not develop any axillary structure at all, but the apex of the stem divides into two equal parts, one of which develops into the female inflorescence, while the other continues as the main axis of the stem, which is therefore not such a sympodial structure as Schumann and Irmisch supposed. The stamen bears precisely the same relation to the lateral branches that the female inflorescence does to the main axis; i. e., there is a division of the axillary primordium into equal parts, one of which becomes the stamen, the other the lateral branch, which is, therefore, not to be considered as an axillary structure arising from the basal leaf of the staminal shoot.

## II. THE STEM-APEX.

The apex of the shoot is occupied by a more or less conical growing point, whose tissues show the usual arrangement, but the appearance varies a good deal, depending upon the stage of development of the appendicular organs. The general arrangement of the latter is well shown in fig. 83. At the base of the apical complex is the sheath *(sh)* formed at the base of each node of the stem. Above this are the two leaves ($l^1$ and $l^2$), and in the axil of the lower one is the primordium ( ♂ ), which later gives rise to the stamen and lateral branch. The prominence *(x)* at the apex, on examining the neighboring sections of the series from which the figure was drawn, is seen to be one of two, lying side by side and apparently resulting from a true dichotomy of the stem-apex. A somewhat older stage is shown in fig. 85, cut nearly at right angles to this view. At first it is impossible to say which of these is to continue the growth of the stem and which is the young inflorescence; but this is soon determined by the rapid broadening of the floral rudiment.

A cross-section of the staminal primordium shows it to be very early much extended laterally (fig. 84), and it soon divides into two equal parts, one developing into the stamen, the other into the lateral branch, in precisely the same way as in *Naias*. The structure of the stem and arrangement of the vascular bundles is much like *Naias*, but those of the latter are better developed, especially as to the tracheary tissue, which is conspicuous in the younger parts of the bundles, but as in *Naias* becomes mostly destroyed by the subsequent lengthening of the internodes. A single strand passes from the single axial bundle of the stem into the lateral appendages, leaves, flowers, and lateral branches. The structure of the bundle is concentric throughout. In the stem the central strand of tracheary tissue is finally replaced by a large canal (fig. 125). The rest of the bundle is made up of thin-walled conducting tissue, and the whole shows a well marked endodermis. The air-spaces are more numerous than in *Naias flexilis* and not quite so symmetrically arranged.

The leaves show two rows of large intercellular spaces on either side of the mid-rib, and these spaces are separated from each other by diaphragms at pretty regular intervals. The whole structure of the stem and leaf is very similar to that of other submerged aquatics. The sheaths below the nodes are usually not symmetrical, one side being higher than the other (fig. 81, *sh*), and are usually regarded as leaves destitute of a proper lamina. They are of very delicate membranaceous texture and composed of two layers of cells. They show no trace of a vascular bundle or mesophyll.

The squamulæ are conspicuous in *Zannichellia;* their cells are filled with granular protoplasm and the nuclei are large. Their whole aspect is that of secretory cells, and the mucilaginous matter which is found about the younger parts of the plant probably arises from them.

## III. THE ROOTS.

The roots occur in pairs at the nodes and are slender and unbranched. Their most remarkable peculiarity is the presence of a definite dermatogen extending over the apex, quite distinct from the periblem below it and the calyptrogen outside. In fig. 126 is shown a longitudinal section of the root-apex, in which the arrangement of the primary tissues can be easily followed. The periblem is referable to a single layer of cells, which divide rapidly by longitudinal walls back of the apex, so that the ground-tissue becomes many layered in the older parts of the root. The epidermis, as already stated, is continuous over the apex, outside of which lies the massive root-cap, whose growth is due to the rapid multiplication of the cells of its inner layer. This type of root is an unusual one, and according to De Bary (1884, p. 9) is known only in two other plants—*Pistia stratiotes* and *Hydrocharis*. Another unusual appearance observed in *Zannichellia* was the presence of what looked like secretory cells in the epidermis of the root. These are shown in fig. 127. They differ from the neighboring cells in their compressed form, dense contents, and large nuclei.

## IV. THE MALE FLOWER.

Of the two parts into which the staminal primordium is divided, one lies nearer the main axis, and this one becomes the stamen. It is at first scarcely distinguishable in form from its twin structure, the young lateral shoot; but it very soon broadens above, while the base grows but little in diameter and forms the filament, the enlarged end being the young anther. At this stage it resembles curiously in form the young sporophyll of *Equisetum*. There is formed about the base of the whole complex, a rudimentary sheath, homologous with that about the stem-apex, but usually inconspicuous and easily overlooked. Schumann (1892, p. 160) denies the presence of such a sheath, although both Irmisch and Eichler have described it. In a number of the specimens examined by me, however, there was no question as to its presence, although, as usual with the sheaths in the main stem, one side (the inner) is usually higher than the other; so that here the outer margin may be almost or quite abortive. It is, however, extremely likely that Schumann (l. c., p. 161) really saw this but mistook it for anther structure. He describes what he calls a "Vorblatt," which, as he says, is never found in the "branch from the upper sheath-leaf." From a study of Schumann's figures and my own preparations, I am strongly inclined to believe that what Schumann supposed to be a special subtending leaf is in reality the inner margin of the sheath at the base of the staminal complex, which was not developed, or only slightly so, on the outer side.

The origin of the sporogenous tissue of the anther is not easy to trace, as the archesporial cells are at first hardly distinguishable either in form or contents from the adjacent cells. As soon as they are recognizable there is already a group of them whose relation to each other is not entirely clear. The archesporium is developed at four points, and in this respect, as well as in the general structure of the older anther, *Zannichellia* is very different from *Naias flexilis* and resembles more the typical Angiosperms, with their four loculi in the anther. Whether these four loculi are to be considered as each homologous with the single one in *Naias flexilis*, or whether the latter is to be considered as made up of four confluent loculi, is a question which it is not now possible to answer. It will first be necessary to study the development of the anther in some species of *Naias* which is normally quadri-locular.

The anther grows rapidly and becomes longer proportionately, and with this there is a rapid growth and division in the sporogenous tissue. The latter is not clearly delimited in longitudinal sections, but in transverse sections the four groups of sporogenous tissue are more clearly defined. The structure of the anther at this stage shows nothing peculiar. As the stamen grows older the superficial cells have their walls thickened and are quite different in appearance from the cells beneath them (fig. 89). The sporogenous cells are now better marked and show the larger nuclei and denser contents usual in similar cells. Surrounding the masses of sporogenous cells are about three layers of cells forming the tapetum. These, as usual, are almost completely absorbed when the anther is mature. No especial study of the development of the pollen was made, as there seemed to be no peculiarities worthy of note, except the fact that not all the sporogenous cells give rise to spores; but a certain number are broken down and their free nuclei can be observed among the young spores (fig. 91, *b*). This recalls the similar behavior of the sporogenous cells of *Equisetum*. The pollen-spores are small globular cells, which contain two nuclei at maturity, a large vegetative nucleus, and a small generative one contained in a separate antheridial cell (fig. 91). Like the pollen-spores of *Naias*, no exospore is developed, and the ripe spore contains numerous starch granules.

A striking feature of the stamen is the development of its apex into a prominent appendage made up of large cells (fig. 90). The filament is traversed by a vascular bundle, which has a strand of tracheary tissue, showing in section usually two tracheids.

## V. THE FEMALE FLOWER.

The pistillate flowers of *Zannichellia* form a cluster at the end of a short branch, the whole inflorescence being surrounded by a bell-shaped envelope of membranaceous texture, very like the similar sheaths below the nodes of the main axis. Botanists usually regard this whole carpellary complex as a single flower, and Magnus (1894, p. 223) compares it to the single flower of *Naias* and considers the envelope as the homologue of the carpellary envelope in the latter. Morong (1893, p. 56) in his description of the plant, however, evidently considers each carpel as a distinct flower, a view whose correctness is borne out by the study of the development. The number of carpels in a cluster varies from two to about eight. In the form studied by the writer there were usually five.

Each flower consists of a single flask-shaped carpel (fig. 104), having the ovary almost globular in form, and the style expanded above into a peltate stigma, which is much more strongly developed on the outer side, and whose edges are more or less evidently lobed. A very evident canal traverses the style. Schumann, following Irmisch, considers the inflorescence (or "flower") as the termination of the main axis, which is then replaced by a lateral shoot; but we have already seen that this view is incorrect, and the inflorescence is the result of the dichotomy of the main shoot, whose other member continues the growth of the axis.

Very soon after the stem-apex is divided, the young inflorescence becomes recognizable by its broadened form, the other member of the dichotomy remaining more pointed (fig. 85). It is soon evident that the broadening of the floral branch is due to a second dichotomy in it. The branch at this time closely resembles the young staminal one, but is somewhat larger. The arrangement of the tissues is very plain. The epidermis is separated from the axial plerome by a layer of periblem, which is more strongly developed on the lower side of the branch. At the time of the first dichotomy, the plerome consists of four rows of cells (seen in longitudinal section), but at the top it forks, one branch going to each of the branches of the inflorescence (fig. 92). In case there are but two carpels, there is no further division; but in all the specimens examined by me the dichotomy was repeated in each branch. The fifth carpel presumably is formed by a third dichotomy in one of the secondary branches, and where there are eight, it is natural to suppose that all of the branches have divided. It is plain from this that the so-called flower is really a branch system, arising by a true dichotomy of the primordium in precisely the same way that the latter arose from the dichotomy of the apex of the main shoot of the plant. Although the matter was carefully investigated there was no evidence that the flowers ever arose as lateral branches of a common axis.

The early stages of the development of the flower have been investigated by Schumann (1892) and Magnus (1894), but owing to the impossibility of tracing out the youngest of the stages except by the aid of microtome-sections, they failed to make out correctly the origin of the carpels, and especially the real nature of the ovule. Both describe the carpel as arising in the form of a ring-shaped wall, upon whose inner surface the ovule is formed as a secondary growth. A complete study of microtome-sections, through all the younger stages of the flower, has convinced me, however, that the ovule is really an axial structure, being the termination of a branch, and the carpellary leaf merely subtends it.

If an exact median section through the youngest stage in which the flower can be recognized is examined, it will be seen to consist of a very slightly elevated protuberance (fig. 93, *o*), which is the apex of the very short branch resulting from the last dichotomy of the floral axis. On the outer side of this is a crescent-shaped ridge, partially surrounding the apex, in section appearing as a pointed, almost horizontal protuberance (fig. 93, *c*). This is the carpellary leaf, but as its position shows, it is a structure entirely independent of the apex (*o*), or perhaps it may be better considered to be an appendage of it. The true relation of the two structures is still more evident in a later stage (fig. 94), where the tissues of the apex (*o*) show all the characters of the ordinary stem-apex. The base of the carpellary leaf extends around the base of the shoot and is confluent to some extent with it; but in no case do the two form a circular ridge of uniform height and thickness such as Schumann (1892, Pl. V, fig. 3) figures and describes as a circular carpel upon whose inner face the ovule arises later. If we compare with the stage just described a somewhat older one (fig. 95), it is seen that the growth on the side of the apex which is turned away from the leaf is stronger than it is on the inner side, so that the apex itself is beginning to be pushed over toward the inner face of the carpellary leaf. This continues until there is a ridge formed on the outer side of the shoot-apex, which is continuous with the margin of the growing carpel, and the two together constitute a tubular envelope extending above the shoot-apex and completely enclosing it (figs. 96, 99). The latter has been now forced over to a horizontal position by the strong growth on one side and forms a hemispherical projection, the young ovule, which has been erroneously supposed to be an outgrowth of the carpel itself. It is perfectly plain, however, from a study of its development, that the ovule is really the apex of the floral shoot, in which respect it may be compared directly to that of *Naias*. It is quite probable that a similar condition may be found in other low Monocotyledons. Thus in *Sparganium* the description and figures given by Dietz (1887, p. 45, Pl. III, fig. 15) would point to a similar origin for the ovule, although he states that the ovule arises from the wall of the circular carpellary leaf, which, however, is described as being very much higher on the side opposite the ovule.

The development of the ovule itself follows the normal type. The archesporial cell is very early evident as a large hypodermal cell (fig. 97), and can be detected before there is any appearance of the ovular integument, and while the ovule still has the form of a very broad but shallow prominence. From the primary archesporial cell there is cut off a single tapetal cell (fig. 98), and at about the same time the first integument becomes visible as a low ridge extending around the base of the ovule. The nucellus continues to grow, but remains relatively broad, and the apex is almost flat. The tapetal cell divides into two (figs. 100, 101), and the inner archesporial cell rapidly grows and divides so as to form, in all the specimens seen, a row of three cells, distinguished as usual from the neighboring cells by their size and contents. The lower cell is smaller than the others, and to judge from the appearance of sections studied (figs. 100 and 101), the upper and not the lower of the cells gives rise to the embryo-sac. The outer integument appears about the same time that the first divisions take place in the inner archesporial cell and grows with the developing ovule, but as in *Naias*, remains usually shorter than the inner integument, which forms the micropyle. The appearance of these in the mature ovule (fig. 105) shows nothing peculiar.

As the ovule develops, the growth continues stronger upon its upper side, so that it is forced over more and more, until it hangs almost vertically, having passed through an arc of nearly 180 degrees from the position it at first occupied.

The tube formed by the confluence of the outer margin of the shoot and the carpellary leaf grows rapidly and forms the cylindrical style, and its upper margins become widely expanded to form the large peltate stigma. There are no secretory papillæ formed within the ovary for the purpose of directing the pollen-tube, but the position of the ovule is such that the pollen-tube must grow along the integument as far as the opening of the micropyle. Whether some substance is then excreted by the ovule, which directs the tube into the micropyle, it would be difficult to prove; but it is quite probable.

The small size of the pollen-spores precludes the possibility of their depending upon the contained starch for the growth of the pollen-tube until it reaches the ovary. It is not surprising, therefore, to find several layers of cells surrounding the canal of the style, with abundant protoplasm and large nuclei, evidently secretory cells, presumably concerned with the nourishment of the pollen-tube in its passage through the style.

The embryo-sac, as usual, arises from one of the archesporial cells which destroys the others, and soon fills the space formerly occupied by them. Owing to repeated divisions in the tapetal cells, the young embryo-sac lies much deeper within the nucellus than was the case with *Naias* (fig. 102). The subsequent development in normal cases is of the usual angiospermous type and the details were not studied. After the nuclear divisions are completed, the egg apparatus and antipodal cells are formed in the usual manner, the latter as in *Naias*, having definite cellulose membranes. As in the latter, the two polar nuclei are much larger than any of the others (fig. 106), the nucleus of the egg cell being the next in size, and both the antipodals and synergidæ showing small nuclei. After these structures are formed there is a very decided enlargement of the embryo-sac before fertilization is effected, and during this growth it encroaches a good deal upon the surrounding tissues of the nucellus, but it does not occupy so large a space relatively as in *Naias*. Both the antipodal cells and those of the egg apparatus increase very much in size, and this is accompanied by a corresponding enlargement of their nuclei, especially that of the egg (fig. 108). The egg apparatus does not differ essentially from that of *Naias;* but the cells are all somewhat larger and not attached by so broad a base to the upper end of the embryo-sac.

The process of fertilization was not followed out in detail; but in one instance (fig. 108) the pollen-tube was seen entering the embryo-sac. So far as could be judged, the process was identical with that of *Naias*, but only one generative nucleus was observed in the tube. As in *Naias*, the pollen-tube pushes its way between the terminal cells of the nucellus and through the end of the embryo-sac, being much compressed above the point where it enters the sac.

Several cases were noticed where there was a departure from the normal type of development. The most common was an increase in the number of antipodal cells from three to four or five. This is obviously due to a secondary division of one or two of the primary antipodals.

A very much more marked departure from the type is that shown in fig. 110. Here the number of nuclei was much larger than usual, although it was difficult to determine just how many were present, as some of them were poorly defined. Two, which seemed to represent the polar nuclei, were distinct, and the three antipodal nuclei were pretty clear, but the others which were scattered through the granular protoplasm, which filled the whole cavity of the embryo-sac, showed no definite arrangement and did not stain strongly, so that the number could not be satisfactorily determined.

## VI. THE EMBRYO.

The changes following fertilization in *Zannichellia* are the same as in *Naias*. One of the synergidæ persists for a short time, and the fertilized egg elongates before dividing. The latter has a rather broader base of attachment in *Zannichellia*, so that as soon as the first division in the embryo is completed, the suspensor cell already is decidedly larger than the embryo cell. As in *Naias*, the basal cell (suspensor) begins to enlarge at once, but undergoes no further division[1].

A curious variation was met with in one case shown in fig. 119. Here it looks as if one of the synergidæ had persisted and grown with the developing embryo, which was in contact with it on one side for nearly its whole length.

The following divisions in the embryo cell correspond closely to those in *Naias*, but here there seems little doubt that sometimes, at least, the two basal segments of the embryo are formed by division of the lower of the two cells into which the embryo cell first divides. It now consists of three cells (exclusive of the suspensor), and the next wall is in the terminal cell. This wall is nearly vertical (fig. 114), but not infrequently is more or less decidedly oblique. The exact succession of the subsequent divisions was not followed, but there are formed a series of transverse walls in all the primary segments, and also intersecting vertical walls in the upper ones, so that the embryo shows in its upper region a somewhat variable number of segments which are divided into quadrants, and these are separated from the suspensor by two or three undivided basal segments (fig. 116). The number of transverse divisions in the young embryo is greater than in *Naias*, and in consequence the mass of cells constituting the embryo proper is more elongated in the early phases of development.

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[1] Magnus (1870, p. 31) refers to this enlarged basal cell in *Zannichellia*, but gives no further particulars concerning the embryo.

A more marked difference is seen, however, when we study the relation of the members of the embryo to the primary segments. In *Naias*, as in *Alisma*, the whole of the terminal segment develops into the cotyledon, while the stem-apex originates from the second segment. In *Zannichellia*, on the other hand, both stem-apex and cotyledon arise from the terminal segment, the separation of the two being determined by the first vertical wall in that segment; *Zannichellia*, therefore, forms another exception to the rule in Monocotyledons, that the stem-apex is of lateral origin. Solms-Laubach (1878) has shown a similar terminal origin for the stem in several members of the Commelynaceæ and Dioscoreaceæ; and Hegelmaier's (1874, fig. 33) figures of *Sparganium* and *Pistia* indicate that in these forms also the stem-apex is derived from the terminal segment of the embryo; but he makes no statement as to this. Solms' figures of *Heterachtia*, one of the Commelynaceæ, are strikingly similar to corresponding stages in *Zannichellia*, except for the almost complete absence of the suspensor.

The whole of the central region of the embryo of *Zannichellia* goes to form the root, the lower ones contributing to the root-cap, which is here well developed, and the secondary suspensor cells, of which there may be as many as four between the root-cap and the primary enlarged suspensor cell, which finally attains a very large size. As in *Naias*, the suspensor cell has densely granular contents and a very large nucleus.

The separation of the tissue-systems of the embryo is not determined so early in *Zannichellia* as in *Naias*, and the young embryo (fig. 117) shows a less symmetrical arrangement of the cells, the limits between the segments not being always perfectly definite. The formation of the dermatogen is not determined by the first periclinal walls in the segments, but is secondary; the first longitudinal walls cut off the plerome, and this is then followed by a separation of periblem and dermatogen in the peripheral cells.

## VII. THE COTYLEDON.

The cotyledon is formed from one of the two cells into which the terminal segment is first divided. If the primary division is oblique it is the larger of the two cells which forms the cotyledon. In any case the latter grows more rapidly than the stem-apex, and is soon evident as a protuberance on one side of the apex (fig. 118), which continues to increase in size until it assumes a distinctly conical form. Its subsequent growth is very much like that of *Naias*, the main difference being the less completely developed sheath at the base and the characteristic elongated and outwardly curved apex (fig. 124). Owing to the slighter development of the stipular sheath, the cavity thus formed and surroundding the stem-apex, is not completely closed in front.

## VIII. THE STEM.

The young stem-apex (fig. 118, *st*) is covered with a well defined epidermis, continuous with the rest of the embryo, and beneath this is a single layer of periblem cells, separating the epidermis from the plerome, which is connected directly with that of the cotyledon and root. As the embryo enlarges the stem-apex becomes more prominent and forms a projecting almost hemispherical prominence within a well marked cavity formed by the encircling base of the cotyledon (fig. 120). From it is formed later the second leaf (fig. 121, $l^2$). This arises as a protuberance upon the side of the stem-apex, opposite the cotyledon. Its tissues are continuous with those of the stem and show the same relative arrangement.

## IX. THE ROOT.

As might be expected from the larger part of the young embryo which takes part in its formation, the primary root in *Zannichellia* is relatively larger than in *Naias*. The greater part of the root is formed from the second and third of the primary segments of the embryo, and in consequence is longer than that of the same stage in *Naias*. These segments probably always undergo regular quadrant divisions, and then each quadrant cell divides into an inner and an outer cell, the former contributing to the plerome. The separation of the dermatogen follows next, and this is soon followed by a second periclinal wall within the periblem, which thus becomes two-layered. All these tissues are more clearly defined in the root region of the embryo than in either the cotyledon or stem (fig. 118). The plerome extends only to the limits of the third primary segment, as in *Naias*, and from the fourth segment is developed the layer of periblem cells, and later the dermatogen. From the two segments below this layer are formed the cells of the root-cap, which is a conspicuous feature of the root. In most of the sections of the older embryos examined, there was a single layer of initial cells, common to dermatogen and periblem (figs. 122, 123), so that directly at the apex the plerome was separated from the inner cells of the root-cap only by a single layer of cells; but finally there is developed a dermatogen continuous over the apex and distinct from the periblem initials, such as we have seen occurs in the roots of the adult plant.

The end of the root is broad and truncated and the root-cap forms a lenticular body covering only the middle of the flattened root-apex (figs. 122, 123). At the time that the embryo is fully grown, the root-cap is about four cells thick in the middle where the growing part is situated.

The plerome is very sharply defined in the root of the fully grown embryo (fig. 123) and is more massive than in *Naias*. It does not show any evidence of a single initial cell at the apex, nor was any sign of the formation of tracheary tissue observed in any of the embryos examined. This probably is first formed after germination begins.

## X. THE ENDOSPERM.

The endosperm formation corresponds very closely to that described for *Naias*. There is probably a fusion of the polar nuclei, but this could not be positively shown in all cases, and possibly may not always take place. As in

*Naias*, there is evident soon after fertilization a large nucleus just above the antipodal cells, which undergoes no division but increases very much in size. This is more variable in size than in *Naias;* not infrequently it could not be detected in the later stages, and in several instances it looked as if it were undergoing disintegration. The thick nuclear segments, which are usually so conspicuous in *Naias*, are much less so in *Zannichellia*, where the nucleus presents a more uniformly granular appearance. Whether this nucleus is in any cases the original lower polar nucleus must remain for the present unanswered; but it is by no means impossible. The secondary endosperm nuclei, which as in *Naias* arise entirely from the upper of the two primary endosperm nuclei, are rather more conspicuous, having a very definite contour and large nucleolus. They do not divide in the later stages of development of the embryo-sac, but increase a good deal in size. The formation of walls in the endosperm is either rudimentary or entirely wanting.

### XI. The Fruit.

No particular study of the development of the fruit was made, but a few notes were taken which are here given. The outer tissues of the nucellus remain evident at the apex and base, but on the sides are almost completely destroyed by the growing embryo-sac. The thin testa of the seed is formed almost entirely from the outer integument. The walls of the ovary become much thickened and form the firm pericarp of the ripe fruit, and the style persists as a conspicuous beak at its upper end.

## SUMMARY AND CONCLUSIONS.

### A.—Naias.

1. A study of the development of *Naias flexilis* has confirmed the view as to the axial nature of the stamen and ovule.
2. The presence of tracheary tissue in stem, leaf, and

pedicels of the flowers was demonstrated, contrary to the conclusions of Magnus with reference to all species described by him.

3. The anther of *N. flexilis* is regularly unilocular, but not infrequently shows traces of a division into two loculi, which occasionally may be complete.

4. The large pollen-spores contain at maturity three nuclei, one vegetative and two generative. The early growth of the pollen-tube is entirely at the expense of the starch in the spore; only after it has penetrated into the ovary is it nourished by the cells of the pistil. In the ovary there are secretory papillæ at the opening of the canal of the style and also at the base of the funiculus.

5. Fertilization is of the usual type.

6. The first division of the embryo is transverse and divides it into two cells, suspensor and embryo cell. The former remains permanently undivided.

7. The embryo cell divides by transverse walls into a series of segments of which the terminal one forms the cotyledon; the second, the stem; the third and fourth, the root; the others, the secondary suspensor cells. No root-cap is present.

8. It is doubtful whether there is always a fusion of the polar nuclei. There is always present subsequently a single large nucleus at the base of the embryo-sac, which may perhaps represent the unchanged lower polar nucleus. Secondary endosperm nuclei are all derived from the upper of the two primary endosperm nuclei. The endosperm is rudimentary.

9. Deviations from the normal type of embryo-sac were noted in several cases.

### B.—Zannichellia.

1. The anthers and ovules of *Zannichellia* like those of *Naias* are strictly axial structures.

2. The female infloresence is formed by the dichotomy of the main axis, but is not, as has been claimed, the

transformed axis itself; the carpels, or individual flowers, are formed by repeated dichotomy of the primary floral axis.

3. The envelope about the infloresence is the homologue of the tubular bract below each node of the main axis.

4. The male flower is also strictly terminal and arises by the dichotomy of a primordium in the axil of the lower of the two foliar leaves at each stem-node. The sister shoot developed from the primordium becomes a lateral branch.

5. The stamen corresponds closely in structure to the ordinary angiospermous type. The pollen-spores are small, with two nuclei at maturity; a conducting tissue is developed about the canal of the style, which nourishes the pollen-tube.

6. The ovule, like that of *Naias*, is the transformed apex of the floral axis.

7. The embryo-sac generally arises from the upper cell of the sporogenous complex; its development is normally of the ordinary type.

8. The first divisions in the embryo correspond to those in *Naias flexilis*.

9. Of the segments of the embryo cell, the terminal one gives rise to both cotyledon and stem-apex; the second, third, and fourth to the root, and the fifth to the root-cap; a secondary suspensor of three or four cells is developed from the lower segments.

10. The development of the endosperm is essentially as in *Naias*.

11. Abnormal embryo-sacs much like those in *Naias* were met with.

12. The primary root of the embryo, as well as those of the mature plant, have four distinct meristems; i. e., plerome, periblem, dermatogen, and calyptrogen.

Comparing *Naias* and *Zannichellia*, there are obviously many points of structure in which they agree. The general arrangement and development of the stem and leaves agree closely in the two, and the arrangement of the tissues is very similar. The origin of the flowers, too, as we have endeavored to show, is essentially the same in the two genera, although in *Zannichellia* the flowers are much better developed than in *Naias*. Whether the quadrilocular anther of the former is to be considered as derived from the unilocular form found in *N. flexilis*, through forms like *N. major* for example, can be better answered after the development of the anther in the latter has been more carefully studied.

Corresponding to the more highly developed flowers in *Zannichellia*, the tissues of the stem, especially the vascular bundles, are much better developed. Whether the same difference exists in the roots of the mature plants as is found in the embryos cannot now be stated. A further study of this point would be interesting.

The embryos of the two agree closely in their earliest divisions, and in both the suspensor remains permanently undivided. It is extremely probable that a further study of embryos of the same type will show that this is a common if not universal phenomenon. In regard to the origin of the different members of the embryo, however, there is one important difference; viz., the origin of the stem-apex from the terminal segment in *Zannichellia*. In this respect the latter approaches several Commelynaceæ and Dioscoreaceæ described by Solms-Laubach (1878), where there is a similar terminal origin for the stem-apex. This type of embryo is probably more common than has been supposed, as Hegelmaier's figures of *Sparganium* (l. c.) indicate a similar state of affairs there.

Corresponding to the greater part of the embryo devoted to its formation, the root in *Zannichellia* is better developed than in *Naias*, and the absence of a root-cap in the latter is also noteworthy, as this is a very uncommon phenomenon.

Comparing the embryos with those of other Monocotyledons, it is seen that in regard to the formation of the cotyledon and stem-apex, *Naias* approaches the type of *Alisma* and the Liliaceæ, while *Zanichellia* is more like the type of the Commelynaceæ or Dioscoreaceæ, where the stem-apex is terminal.

Attention has been called by the writer (Campbell, 1891, p. 253; 1895, p. 518) to the resemblance between the embryo of *Isoetes* and that of the typical Monocotyledons; and Kny (1875) has also suggested an independent origin for Monocotyledons from the Filicineæ. The lateral origin of the stem-apex in *Isoetes* is certainly suggestive of the similar origin in *Naias* or *Alisma*, and Hegelmaier's figures of *Pistia* are still more suggestive of the embryo of *Isoetes*, especially in the complete absence of a suspensor. The figures which Solms-Laubach gives of the embryo of *Heterachtia*, where the suspensor is also absent, are remarkably like the embryo of a typical Fern.

The ovules and anthers of *Naias* probably show the closest approach to the sporangia of the Pteridophytes of any angiospermous plant. The homologies of the ovules and pollen-sacs of the latter with the sporangia of the former have of course been recognized for a long time. The remarkable similarity to each other of ovule and anther in *Naias*, even to the investment of the anther with an integument like that of the ovule, is noteworthy as pointing to a very primitive condition in the differentiation of the macro- and microsporangia. It will be borne in mind that in all heterosporous Pteridophytes the two sorts of sporangia are much alike in their earlier stages of development, and it is extremely interesting to find an angiospermous Spermaphyte which so nearly resembles typical Pteridophytes in this respect. The writer, in a study of the sporangia in *Azolla* (Campbell, 1893, p. 162), has called attention to the remarkable resemblance between the macrosporangium there and the ovule of the Angiosperms, a resemblance that did not escape the earlier students of this plant. In this paper I defended the view that the indusium in *Azolla* is the homologue of an ovular integument, a view which I see no reason now to retract. The suggestion has also been made that possibly the velum in *Isoetes* may be of the same nature. It is true that these may be only analogies, but they are in any case of great importance, as showing how closely related, structurally at least, are the sporangia of the Pteridophytes and Spermaphytes. The different origin of the sporangia in *Naias* and *Isoetes*, however, as well as other structural differences, does not admit of any very close connection between such forms, and it would be useless to attempt a detailed comparison of the Monocotyledons and Pteridophytes until a great many more types of the former have been critically examined, especially those whose embryos are more like those of the Pteridophytes than is that of *Naias*.

The occurrence of deviations from the ordinary structure in the embryo-sac in both *Naias* and *Zannichellia* suggests the importance of further investigations on this point, as it is here that the surest clues to relationship with the Pteridophytes, if such exist, are most likely to be found. Recent investigations in this direction have shown that the type of structure is not so uniform as has generally been supposed, this being especially true with respect to the number of the antipodal cells. In both *Naias* and *Zannichellia* we have also seen that the number of nuclei, apart from the antipodal cells, may be considerably augmented. A few observations were made by the writer upon *Sparganium eurycarpum*, which showed that in this plant also the structure of the embryo-sac is not always constant. In fig. 129 is shown a case where there were about ten free nuclei in the upper part of the sac, and four very prominent antipodal cells. The latter may reach an extraordinary development in this species, as is shown in fig. 130. Other variations from the type were seen in the same species, although as yet these have not been critically studied. These instances are sufficient to show that there is much more variability than is usually supposed, and a further examination of these same parts in other low monocotyledonous types may be expected to yield further instances of the same kind.

The question of the position of the Monocotyledons in the system, and the relative positions of their different orders, is by no means settled. There is, however, a growing tendency to regard them as the most primitive of the Angiosperms, and not as Strasburger has suggested, a group derived originally from the Dicotyledons. So, again, as to the relative positions of Gymnosperms and Angiosperms, the writer has already expressed his belief that these two great divisions of the Spermaphytes are of entirely distinct origin. If we accept the view that there is a probable direct connection of the Monocotyledons with the Pteridophytes, it is among just such simply organized aquatics as *Naias* or *Zannichellia* that we should naturally look for the point of contact. It is true that these are generally looked upon as degenerate types derived from apocarpous forms, like *Alisma* or *Butomus* (Delpino, 1896; Bessey, 1893); but there seems no good reason for such an assumption. Inasmuch as nearly all the heterosporous Filicineæ, including *Isoetes*, are either aquatic or at least amphibious, it would naturally be expected that forms derived from them would inherit their aquatic habits, and the simple tissues which accompany such a habit. We should also expect in such forms an extremely simple type of flower, such as really exists in *Naias*. Taking into account, then, all of the similarities of the tissues of the mature plants, as well as the similarities in the embryo and sporangia, it may safely be said that at any rate the theory of a direct derivation of the Monocotyledons from forms related to the heterosporous Filicineæ, and especially the Isoetaceæ, is not weakened by what has been brought out in the course of these investigations.

As to the relationship of *Naias* and *Zannichellia* to each other, it does not seem sufficient to warrant uniting them in the same family, although they are with little question not very distantly related. For a clear understanding of their relationship to the other apocarpous Monocotyledons, further investigations of these forms will be necessary before we are in a position to decide with any degree of certainty.

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January, 1897.

## SUPPLEMENTARY NOTE.

Since the foregoing paper was completed I have procured a copy of Hofmeister's paper (1861), in which he gives a somewhat extended account of the development of *Naias major* and a less complete description of the embryo of *Zannichellia*. In both cases he figures and describes correctly the earliest phases of the embryonic development, including the enlarged suspensor cell, but the details concerning the embryo-sac and the later stages of the embryo are very incomplete. No details are given as to the arrangement of the tissues in the older embryos, nor does he seem to have noted the absence of a root-cap in *Naias*.

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## EXPLANATION OF FIGURES.

### PLATE I.

Fig. 1. Stem-apex of *Naias graminea* Del., showing the arrangement of the appendicular organs—*ff′*, *ff″*, *ff‴*, fertile leaves; *fst′*, sterile leaf; *fl′*, *fl″*, floral rudiments; *f′*, *f″*, lateral branches (after Schumann).

Fig. 2. This and all the succeeding figures are drawn from the author's own preparations of *N. flexilis* Willd. Fig. 2 is a cross-section of the terminal bud, × about 70. The older leaves are numbered; *x*, *x′*, the apices of the main axis and oldest branch, *sq.*, squamulæ intravaginales; ♀, ♀′, ♀″, young female flowers.

Fig. 3. Longitudinal section of the stem-apex, × about 200; *v*, stem-apex; *k*, young primordium, subtended by the leaf, *l*; ♀, young female flower.

Fig. 4. Longitudinal section of an abnormal stem-apex, where the primordium had developed directly into a lateral sterile branch, *v′*; × about 400.

Fig. 5. Longitudinal section of a normal stem-apex, showing the youngest pair of leaves, $l^1$, $l^2$, and the primordium, *k*, subtended by the latter; × 400.

Fig. 6. Cross-section of a young internode of the stem, showing the arrangement of the tissues and the intercellular spaces, *i*; × about 300.

Fig. 7. Longitudinal section of a young internode, showing the central annular vessel of the vascular bundle; × 400.

Figs. 8-10. Early stages in the development of the male flower seen in longitudinal section, × about 400; *in*, inner envelope (integument); *p*, outer envelope.

Fig. 11. Section of a young primordium divided into the floral rudiment, *f*, and the lateral branch, *v*. The subtending leaf is seen below.

Fig. 12. Longitudinal section of male flower after the differentiation of the archesporium; × 200. The archesporial cells are the nucleated ones.

Fig. 13. Cross-section of an older anther.

Fig. 14. Longitudinal section of a male flower shortly before the separation of the sporogenous cells; × 70.

Fig. 15. Upper part of the same more highly magnified. The enlarged upper part of the integument, *in*, is conspicuous.

Fig. 16. Longitudinal section through the base of a slightly older flower, showing a rudimentary partition in the lower part of the theca; × 200.

Figs. 17-21. Successive stages in the first division of the spore-mother-cell. Leitz, immersion $\frac{1}{18}$, ocular 3; reduced by one-third.

Fig. 22. Two pollen-tetrads; × about 400.

Fig. 23. Young pollen-spore, with the primary antheridial cell; × about 800.

Fig. 24. A slightly older stage.

Fig. 25. A nearly mature spore, with the large vegetative nucleus, and the two small generative cells. The spore is nearly filled with starch granules; × about 400.

Fig. 26. A ripe pollen-spore; × 300.

## PLATE II.

All figures refer to *Naias flexilis*.

Fig. 27. Mature male flower, showing the long pedicel; × 25.

Fig. 28. A male flower which has discharged the pollen, showing the lateral rupture of the floral envelope; × 25.

Fig. 29. Longitudinal section of a nearly mature flower, showing a complete division of the anther into two loculi; × 40.

Figs. 30, 31. Germinating pollen-spores; × 400.

Figs. 32, 33. Pollen-tubes, showing the granular protoplasm at the extremity. In fig. 33, the two generative nuclei, *k*, can be seen.

Figs. 34-39. Successive stages in the development of the ovule, seen in longitudinal section; × about 400, (except fig. 37, which is magnified about 200). The carpel is not shown except in figs. 34 and 37. The archesporial cells are shaded; *t*, the tapetum, *in*$^1$., *in*$^2$., inner and outer integuments.

Fig. 40. Young female flower, showing the young spiny lobes, *x*, and stigmatic lobes, *y;* one of the latter is still very small; × about 200.

Fig. 41. Section of young ovule, with the archesporium divided by longitudinal as well as transverse walls.

Figs. 42, 43. Young embryo-sacs, with two and four nuclei; × 450.

Fig. 44. A mature female flower; × 25.

Fig. 45. One of the stigmatic lobes; × 200

Fig. 46. A spiny lobe; × 200.

Fig 47. Longitudinal section of the ovary of a mature flower, showing the stylar canal and papillæ, *p;* × about 60.

Fig. 48. Young papillæ from the upper part of the ovary; × 400.

Fig. 49. Older papillæ from the same place.

Fig. 50. Upper part of mature embryo-sac, showing one of the synergidæ, *s;* the egg, *o;* and the two polar nuclei in close contact, *k;* × 400.

Fig. 51. The two synergidæ from a similar one.

Fig. 52. Egg apparatus from a slightly younger embryo-sac than that shown in fig. 50.

Fig. 53. (*a*) Upper part of the embryo-sac at the time of fertilization; *pt*. the pollen-tube, with two generative nuclei; *o*, the egg.

(*b*) The large endosperm nucleus, probably formed by the fusion of the two polar nuclei.

## PLATE III.

All figures refer to *Naias flexilis.*

Fig. 54. Two sections of an abnormal embryo-sac, in which apparently the upper archesporial cells were not absorbed as is usually the case, and no definite egg apparatus was formed.

Fig. 55. Lower part of the embryo-sac shown in fig. 54, with six antipodal cells (four only are shown in the section).

Fig. 56. Section of an ovule which apparently had not been fertilized; the embryo-sac is replaced by a mass of elongated cells; × 200.

Fig. 57. (*a* and *b*) Two sections through a normal embryo-sac, showing fertilization; *pt*, pollen-tube; *o*, egg; *s*, synergidæ; *k*, endosperm nucleus. (*c*) Lower part of the same embryo-sac, showing two of the antipodals; × 450 (about).

Fig. 58. An abnormal embryo-sac, in which only one cell of the egg apparatus could be certainly distinguished. The end of the pollen-tube was very much enlarged.

(*b*) Antipodal region of the same embryo-sac.

Fig. 59. Endosperm nuclei from an embryo-sac containing an advanced embryo. *(a)* The single large nucleus above the antipodal cells, which undergoes no division; *(b)* The smaller secondary nuclei from the upper part of the embryo-sac; × 400.

Fig. 60. Two sections of the upper part of an embryo-sac, showing the fertilized egg cell, *o*, and one of the synergidæ, *s*, which is still intact.

Fig. 61. (*a*) Upper part of embryo-sac, with two-celled embryo; × 250. (*b*) Endosperm nucleus of the same.

Figs. 62-66. Successive stages of the developing embryo, in longitudinal section; × 250. *sus*, primary suspensor cell; *k*, a secondary endosperm nucleus.

Fig. 67. Cross-section of an older embryo.

Fig. 68. Longitudinal section of an embryo, showing the primary segments 1, 2, 3.

Fig. 69. Longitudinal section of an embryo, showing the enlargement at the base of the cotyledon.

Fig. 70. Two nearly median, longitudinal sections of an older embryo; × 200; *st*, stem-apex; *cot*, cotyledon; in *a*, the boundary of the plerome is indicated by a heavy line.

Fig. 71. Median, longitudinal section of an older embryo.

Fig. 72. Similar section of a much older one; × 70.

Fig. 73. Longitudinal section of an embryo from a nearly ripe seed; × 40.

Fig. 74. Two sections through the apical region of an embryo of the same age as the one shown in fig. 73.

Figs. 75, 76. Median, longitudinal sections through the root of advanced embryos; *pl*, plerome; × 200.

Fig. 77. Root of a full-grown embryo, showing the formation of intercellular spaces.

Figs. 78, 79. Two transverse sections of the root just back of the apex; *v*, vessel; *en*, endodermis; *i*, intercellular spaces; × 400

## PLATE IV.

All the figures refer to *Zannichellia palustris* L.

Fig. 81. Nearly median longitudinal section through the stem-apex; × 70. The actual apex, $x$, was not included in the section, but its position is indicated by the dotted line; *sh*, the sheath below the node; $l^1$, $l^2$, the two "spathe leaves;" *i*, lacunæ in the leaves; ♀, female flowers; ♂, male flowers; *sq*, squamulæ intravaginales; $x'$, apex of a lateral branch.

Fig. 82. Transverse section of the terminal buds. The leaves are numbered; otherwise the lettering as in fig. 81.

Fig. 83. Longitudinal section of stem-apex; × 200. The apex, $x$, was divided into two parts, only one of which shows in the section.

Fig. 84. Transverse section of the staminal primordium; × 400.

Fig. 85. Longitudinal section of the stem-apex after its division into the carpellary branch, ♀, and the secondary stem-apex, *v*; × 200.

Figs. 86-88. Development of the stamen seen in longitudinal section; × 200.

Fig. 89. Transverse section of an older anther.

Fig. 90. Longitudinal section of an older stamen, showing the peculiar terminal appendage; × 60.

Fig. 91. Two nearly mature pollen-spores. In *b*, the primary nucleus is dividing. Two free nuclei, *k*, are shown, derived from disintegrated archesporial cells; × 400.

Fig. 92. Longitudinal section of young female inflorescence, showing the dichotomy of the plerome; × 400.

Fig. 93. A similar section through the margin of an older inflorescence, showing the ovular rudiment, *o*, and the subtending carpellary leaf, *c*.

Figs. 94-96. Early stages in the development of the female flower in longitudinal section; × 400. *o*, ovular rudiment; *car*, carpel.

Fig. 97. Section of the young ovule, showing the primary archesporial cell; × 400.

Fig. 98. Cross-section of a young flower; × 400. *car*, Carpellary leaf; *t*, the primary tapetal cell.

Fig. 99. Longitudinal section of an older flower; × 150.

Figs. 100, 101. Longitudinal section of ovules, showing the later divisions in the archesporium; *t*, tapetum.

Fig. 102. An older ovule, the nucleus of the embryo-sac already divided; × 400.

Fig. 103. Longitudinal section through the inflorescence, showing its connection with the main axis; *sh*, the involuere.

## PLATE V.

All figures except 128 and 129, refer to *Zannichellia*.

Fig. 104. Longitudinal section of a nearly mature female inflorescence; × 40.

Fig. 105. Longitudinal section of a nearly mature ovule; × 200.

Fig. 106. Two sections of an embryo-sac after the formation of the egg apparatus and antipodals; × 400.

Fig. 107. Lower part of a mature embryo-sac, with four antipodal cells; *k*, the lower polar (?) nucleus; × 350.

Fig. 108. Egg apparatus at the time of fertilization; *pt*, pollen-tube; *o*, egg; *s*, synergidæ; × 400.

Fig. 109. Antipodal region of mature embryo-sac.

Fig. 110. Two sections of an abnormal embryo-sac, with numerous free nuclei; × 400.

Fig. 111-116. Successive stages in the development of the young embryo; longitudinal sections × 400. The primary segments are numbered.

Figs. 117, 118. Older embryos; × 200; *st*, stem-apex; *cot*, cotyledon.

Fig. 119. Two sections of an abnormal embryo, in which, apparently, one synergid, *s*, was persistent, and adherent to the embryo; × 400.

Fig. 120. Section of an advanced embryo; × 70.

Fig. 121. Stem-apex of the same embryo; × 200. $l^2$, the second leaf.

Fig. 122. The root of an embryo of the same age. *rc*. root.cap; $sus^2$ secondary suspensor.

Fig. 123. Root of an almost full-grown embryo.

Fig. 124. Longitudinal sections of nearly mature embryos; × 40; *a* shows the stem-apex and root; *b*, the hooked cotyledon.

Fig. 125. Cross-section of an internode from the stem of a mature plant; × 70.

Fig. 126. Longitudinal section of the apex of a root from the mature plant, showing the four primary tissues; plerome, *pl;* periblem, *pb;* dermatogen, *d;* and calyptrogen, *cal;* × 200.

Fig. 127. Epidermal cells from near the root-apex, *a*, surface view; *b*, a vertical section; × 400. The cells with dense contents are apparently secretory cells.

Fig. 128. Embryo-sac of *Sparganium eurycarpum* Englm, with about ten free nuclui, and four antipodal cells.

Fig. 129. Two sections of an embryo-sac of *Sparganium eurycarpum* Englm, showing extraordinary development of the antipodal cells, *ant*.

LELAND STANFORD JUNIOR UNIVERSITY PUBLICATIONS.

## CONTRIBUTIONS TO BIOLOGY
FROM
## THE HOPKINS SEASIDE LABORATORY.

XII.

# Geology of the Paleozoic Area of Arkansas South of the Novaculite Region.

...BY...

GEORGE H. ASHLEY, PH.D.

Reprint from the Proceedings of the American Philosophical Society,
Vol. xxxvi, No. 155.

LELAND STANFORD JR. UNIVERSITY,
PALO ALTO, CALIFORNIA,
1897.

# Prefatory Note.

This memoir is the eleventh of a series designed to illustrate the investigations and explorations of the Hopkins Seaside Laboratory, an adjunct of the biological laboratories of the Leland Stanford Junior University. The series is issued under the patronage of Timothy Hopkins, Esq., of Menlo Park, California. The present paper is published by the American Philosophical Society, appearing simultaneously in its present form and as a part of the Proceedings of that Society.

CHARLES H. GILBERT,
OLIVER P. JENKINS,
*Editors.*

DATE OF PUBLICATION: AUGUST 12, 1897.

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# GEOLOGY OF THE PALEOZOIC AREA OF ARKANSAS SOUTH OF THE NOVACULITE REGION.

BY GEORGE H. ASHLEY, PH.D.,
*Assistant Geologist.*

WITH AN INTRODUCTION BY JOHN C. BRANNER.

(*Read May 13, 1897.*)

## INTRODUCTION.

In 1890–92 Dr. George H. Ashley, the author of the present paper, was entrusted with the study of that part of the Paleozoic region of southwestern Arkansas lying between the Lower Silurian Novaculite area or the Ouachita uplift on the north, and the Cretaceous area on the south. This paper gives the principal results of Dr. Ashley's work. Properly speaking it is a part of the official reports of the Geological Survey of Arkansas, but the survey was abolished by the Legislature in 1893, and no provisions were made for printing the several unpublished volumes.

Mr. Ashley was ably assisted during one field season by Prof. A. H. Purdue, now Professor of Geology at the Arkansas Industrial University, and other valuable additions were made to the work by Mr. John H. Means, who as assistant on the State Survey has worked up the geology of the Lower Coal Measures north of the Ouachita uplift. Some notes were also furnished by Dr. J. P. Smith, formerly assistant geologist on the Arkansas Survey, now Professor of Paleontology in the Leland Stanford, Jr., University. The northern border of the Cretaceous rocks was traced by Dr. O. P. Hay.

The limited time that could be spent upon the geology of the region discussed in this paper, the folded and faulted condition of the rocks, the absence of fossils and the lack of good maps have made it impossible for the author to enter into details regarding the geologic history of the area.

The divisions I have made of the rocks and the reasons for making them are accepted, not as altogether satisfactory, but simply as the best that can be offered under the circumstances. The beds I have called the base of the Coal Measures are the novaculite conglomerates exposed at Hot Springs. The reason for considering these beds as the top of the Lower Silurian or the bottom of the Coal Measures is simply that the novaculites, as considerable beds, end abruptly with this stratum, and because this bed is a conglomerate. It will be seen that there are some thin and unimportant beds of novaculite above this horizon, but they are no more to be compared with the novaculites below it than are the coal beds of the Devonian to be compared with those of the Carboniferous.

So far as I can judge from my own observations there is no marked unconformity between the Lower Silurian rocks and the Lower Coal Measures rocks, and that in spite of the fact that there are no Devonian rocks known to be such in this part of the State. The conglomerate, however, suggests the possibility of such an unconformity, and it is quite possible that the disturbed condition of the rocks has caused such a gap to be overlooked.

Mention is made at several places of a stratum of supposed igneous rocks interbedded with the sedimentary ones, and assumed by Dr. Ashley to be everywhere at the same horizon. There is some doubt in my mind as to whether this bed is everywhere the same, and also as to whether it is really igneous. There is no doubt but that the bed discovered by Dr. J. P. Smith in 5 south, 32 west, section 1, is a tuff, but at other places the rock is so changed by decomposition that it is not possible to say with certainty what the original materials were. It is also suggested by the author that these beds are to be correlated with similar rocks supposed to be volcanic tuffs and found about Cushman, Independence county, in the northern part of the State. But this north Arkansas bed turns out to be a phosphate deposit, and a chemical analysis of one of Dr. Ashley's specimens from southwest Arkansas shows it to contain an equivalent of nine per cent. of calcium phosphate.[1]

To the little proof here given of the age of these Lower Coal Measures rocks should be added that I have found Calamites in this series on the west bank of the Ouachita river in 5 south, 18 west, section 32. Attention should also be directed to the notes of Prof. C. S. Prosser on the "Lower Carboniferous Plants from the Ouachita Uplift," published in the *Novaculite Report of the Arkansas Survey* (Vol. iii, 1890, pp. 423, 424). Prof. Prosser's notes are upon fossils found north of the region described in the present

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See "The Phosphate Deposits of Arkansas," by John C. Branner, *Trans. Amer. Inst. Mining Engineers*, September, 1896.

paper, but the structure of the region shows that they are from rocks occupying the same geologic horizon.

The general structural features of the Ouachita uplift are so much like those of certain parts of the Appalachian structure that one naturally assumes at the outset that we have here an Appalachian type, and indeed a part of the original Appalachian folding. It cannot be stated positively that this is not the case, but it is my own opinion that the Ouachita uplift is the structural equivalent, not of the Appalachians, but of the Nashville Silurian basin and of the Cincinnati arch. To be sure the Ouachita anticline is closely pressed, while the Nashville and Cincinnati folds are very gentle. This difference is, however, a matter of structural detail only. The equivalent of the Appalachian chain and the source from which the Lower Coal Measures sediments of south Arkansas appear to have been derived (in part) was a continuation across the present Mississippi drainage of the pre-Cambrian rocks of Alabama and Georgia, etc. This region, that is the gap through which the Mississippi river now flows, has been lowered, partly by erosion, but chiefly by downward orographic movements and it is now buried beneath the Cretaceous and Tertiary sediments of south Arkansas and of north Louisiana and Texas.

This hypothesis seems to be borne out by the following facts:

I. The fossils found on the south side of the Ouachita anticline are coal plants like those from the Cumberland plateau of east Tennessee, eastern Kentucky, and West Virginia.

II. The sediments thicken and become coarser to the south as one leaves the Ouachita uplift (Ashley) just as in the upper Ohio valley they thicken and become coarser east of the Cincinnati arch.

III. In central Texas, northwest of Austin, is an Archean and Cambrian area which appears to be the southwestern end of the old Appalachian chain, and north of it are Carboniferous rocks.

IV. If the Cincinnati, Nashville and Ouachita arches are assumed to be the same general fold, this line is found to continue into Indian Territory and Oklahoma, and the arch as a whole is parallel with the Appalachian system save across the break made by the present Mississippi river depression where the same conditions would be expected.

V. The peneplain south of the Ouachita mountains and on which the Cretaceous beds were deposited slopes toward the Mississippi.

VI. The Arkansas river drainage formerly (in Carboniferous and

Permian times) flowed westward, but it has been reversed and now flows east and southeast.

VII. The igneous rocks of Arkansas and Texas are mostly along what appears to be the edge—possibly faulted—of this depression.

I have not thought it necessary to exclude or suppress in the present paper statements in conflict with other publications made by the Geological Survey of Arkansas. Reference is here made to the differences between the structural details as worked out by Dr. Ashley and those represented by Dr. Theodore B. Comstock on the map accompanying his report on gold and silver. No geologist with the two maps before him can have any doubt about which is right. It should be said, however, in defense of Dr. Comstock, that the time he could devote to the study of the region on which he had to report was very limited; and in defense of the publication of his map, that the report giving the economic results of his work (and these were correct and of great importance) was so tied to the theory of the structural lines put down on his maps that it was quite impossible to separate the two.

JOHN C. BRANNER,
*Formerly State Geologist of Arkansas.*

## I. GEOLOGIC AND GEOGRAPHIC POSITION.

If in any of the Atlantic or Gulf States, one start from some point on the coast and travel inland, he will, in most cases, observe at one point a striking change both in the topographic and geologic features of the land. He has been traversing at first low-lying, then somewhat more elevated, stretches of level country, characterized, aside from its low elevation above the sea level and comparative flatness, by sluggish, meandering rivers, a luxuriant timber growth, the softness and horizontality of the rocks, consisting of unconsolidated clays, sands, gravels, etc., with an occasional hard layer, and by the freshness of the fossil remains. But as one passes the point mentioned, he comes upon a region of higher altitude, frequently or generally mountainous, with rapid rivers, more hardy but less dense timber growth, the underlying strata being highly consolidated, frequently crystalline limestones, sandstones, shales and granites, in some regions horizontal, in others highly folded and distorted.

A study of the geology on either side of the line of division shows that the region on the coast side is of comparatively recent origin, having been deposited since the close of the Carboniferous age; the harder rocks on the landward side having been deposited during the Carboniferous and preceding ages. The former, which includes the Mesozoic and Cenozoic, has been termed the Neozoic addition. The line between the two has been traced down the Atlantic coast and through northern Georgia, Alabama and Mississippi, thence following the Tennessee river into southern Illinois, where it turns, crossing the Mississippi near Cairo and running approximately southwest on the west side of the St. Louis, Iron Mountain and Southern Railway nearly to Arkadelphia, where it turns westward and follows an irregular line into the Indian Territory and Texas.

The region described in the present report lies in a belt just north of that portion of the above line running west from Arkadelphia. To define and locate it more clearly we shall first review the general geologic features of the region from this line to the Arkansas river as shown in the reports already published upon that area.[1]

The history thus revealed is briefly:

1. A long period of deposition running from early Silurian times through the Carboniferous age, and the accumulation of deposits of great thickness.

2. These deposits give way to mountain-making forces and becoming much folded are lifted into an anticline, called by Dr. Branner the "Ouachita uplift." The axis of this anticline is an approximately east and west line running from Little Rock west well into the Indian Territory.

3. A period of erosion during which the uplift is cut down until the Silurian strata are exposed along the axis. The later beds are successively exposed as one goes away from the axis of uplift.

4. A period of depression and deposition upon the southern slope of the Ouachita uplift. During this period, and up to the present time, there has been a series of oscillations of level, resulting in slight nonconformity between the strata.

The rocks are now exposed in the following order:

1. A belt of Silurian exposures running from Little Rock a little south of west to Dallas, of which the novaculites[2] are prominent

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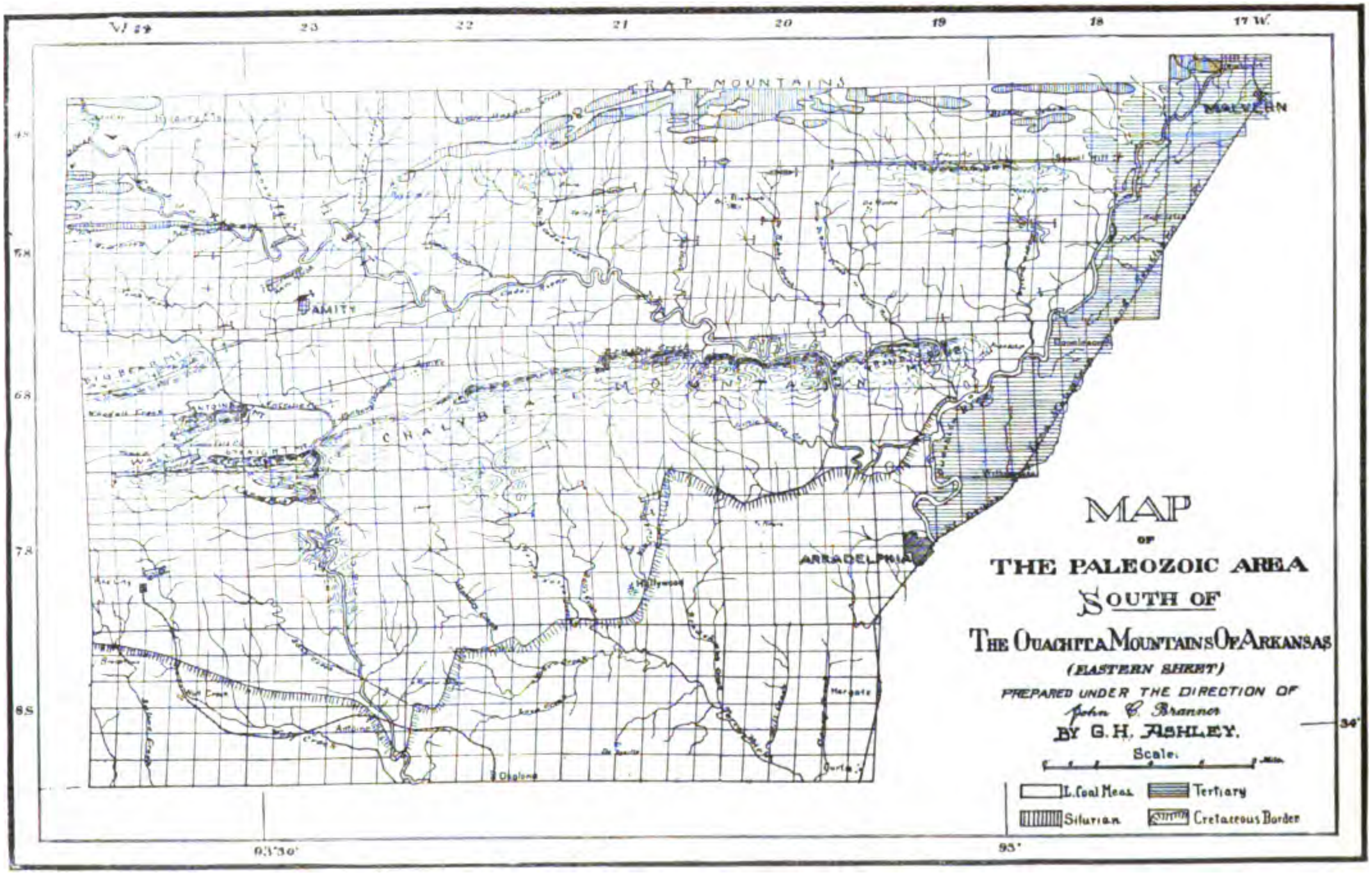
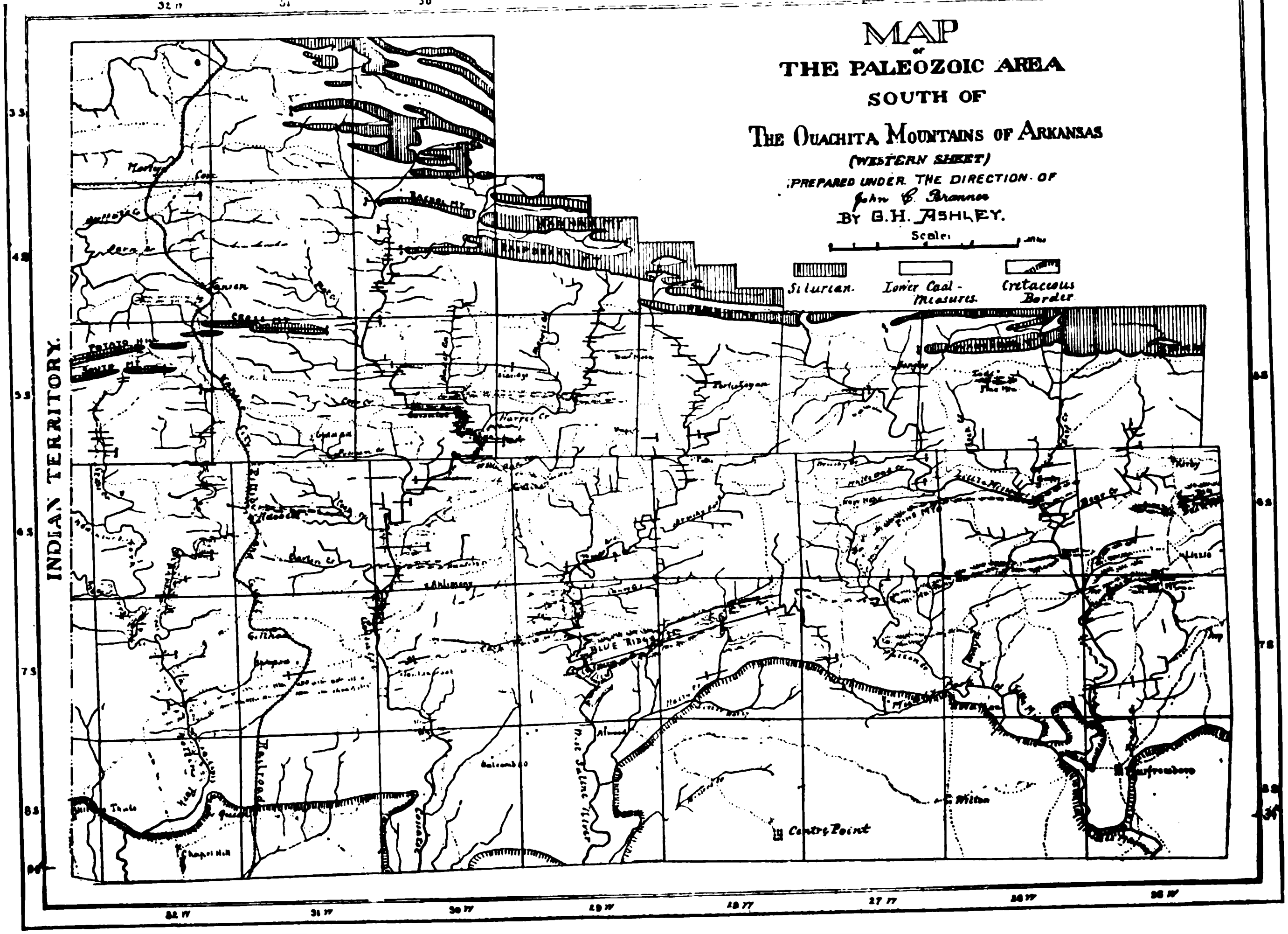
[1] *Geol. Surv. of Ark.*, An. Rep. for 1888, Vol. iii; for 1890, Vols. i and iii.

[2] *Geol. Surv. of Ark.*, An. Rep. for 1890, Vol. iii.



MAP OF THE PALEOZOIC AREA SOUTH OF THE OUACHITA MOUNTAINS OF ARKANSAS (EASTERN SHEET)

PREPARED UNDER THE DIRECTION OF John C. Branner BY G. H. ASHLEY.



# MAP
of
# THE PALEOZOIC AREA
SOUTH OF
THE OUACHITA MOUNTAINS OF ARKANSAS
(WESTERN SHEET)
PREPARED UNDER THE DIRECTION OF
John C. Branner
BY G. H. ASHLEY.

layers. Owing to minor folds some of the higher strata are exposed in this belt.

2. To the north the higher beds are successively exposed, ending in the upper or productive Coal Measures near the Arkansas river.

3. To the south the higher strata are exposed for a short distance, but still further south they are covered by Cretaceous rocks.

4. The Cretaceous and the overlying Tertiary beds extending southward to the State line.

The strata we are to consider are those mentioned under the third head of the preceding paragraph: the beds deposited between the Silurian and the end of Carboniferous times, and exposed south of the Silurian exposures of southwestern Arkansas, and north of the Cretaceous area.

The northern limit of this area is a line starting from Social Hill in 4 S., 18 W., and touching Point Cedar, Rock Creek and Langley, then passing through the centre of township, 4 S., range 30 W., to Potter. West of Potter these beds swing around the end of the Silurian anticlinal nose and unite with the beds of the same age and character lying north of the Silurian area. On the east the boundary nearly follows the Ouachita river to the mouth of the Caddo river, thence on the south the line follows the Caddo and up Big DeGray creek, then turns south to Hollywood, then west, and follows a very irregular line, touching Clear Springs, Antoine, Royston, Nathan, Muddy Fork, Atwood, Ultima Thule, and so on into the Indian Territory.

## II. SALIENT FEATURES OF THE REGION.

*A General Description of the Area.*—The region under consideration is a rocky, hilly country stretching along the south side of the Ouachita mountains. It varies in width from fifteen to thirty miles; the part lying in Arkansas is about ninety miles long. It is for the most part densely wooded and thinly settled. The surface is broken into a great number of valleys and ridges having an east and west trend, with a few narrow and usually rugged north and south valleys. Few, if any, of these ridges are more than three hundred feet in height.

The most common type is a ridge or table land having a steep north face, while the south side slopes away gently. A few are narrow, sharp ridges with uneven crests and steep flanks on both north and south sides. All others may be taken as variations of these two types. Sometimes the ridges can be followed for a score or two of miles; then again a ridge is prominent only where it approaches a north and south stream, and as it recedes from the stream the valleys on either side become shallower until the ridge coalesces with those next north and south of it, and is lost as a distinct ridge.

All around the southern edge of the region, the topography is of quite a different nature. It appears to be very level, though having a slight rise to the north. This level strip averages half a dozen miles in width. Its northern edge is irregular and seems to be governed by the erosion of east and west valleys into what might have been its northward extension. Novaculite gravels cover this flat region. Sandstone is the most common rock, though occasionally in the valley there are considerable beds of shale.

It is a matter of common observation among those living in the region, that the rocks almost invariably "stand on end."

While much of the region is very stony, the rocks are mostly in the form of loose blocks and boulders, but little of it being found in place and most of that is in the beds of streams.

Though the strata usually dip to the south, in some places they dip to the north. The dip is usually high, more often over than under 45°.

Just north of this Carboniferous region are the high hills or mountains of the Ouachita mountain system. The rocks in these mountains are novaculites associated with shales and sandstones.[1]

To the south these Paleozoic beds are overlaid unconformably by sands, marls and limestones of the Cretaceous.

In the eastern part of the region under discussion the main streams run east or southeast and the branches run south. The streams are not rapid and the valleys are frequently quite broad. Westward the main drainage swings around towards the south, the branches run in east-west channels, and the streams are rapid, with narrow, sometimes precipitous banks.

From an economic standpoint the most valuable product of the area is the timber. Hard and soft woods of excellent qualities abound in every part of the region.

Little of value was discovered in the line of building or other stone, nor is the region rich in ores, though small quantities of pay ore, mostly antimony, have been found in the southwestern part of the area.

Corn and cotton are the principal crops. The country as a whole is well watered and healthful.

[1] *Geol. Surv. of Ark.*, An. Rep. for 1890, Vol. iii.

Much of the land is too broken for cultivation except for some hillside crop like grapes, which are said to do well here.

While most of the soil is sandy and not very rich, there is much good land along the streams, particularly in the eastern part. In the western part of the region most of the available land is on the divides.

*Conclusions.*—A summary of the conclusions deduced from a study of the features above touched upon can best be given as a history of geologic events in the region.

*The Periods of Deposition.*—The deposition of the rocks took place before the end of the Carboniferous age, and as the rocks are of both Silurian and Carboniferous ages, it must have been during these times that these sediments were laid down.

The Lower Silurian beds are the novaculites, with the accompanying shales and sandstones. The Carboniferous strata are sandstones and shales, with which occur a little grit, novaculite and some other rocks. No nonconformity has been found between the two sets of beds. The Silurian beds are believed to underlie the sandstones of the Carboniferous over all of the region, though they have been recognized at only one place.

The original thickness of the Carboniferous strata is not known, nor is it known whether the whole or only a part of the Carboniferous series was laid down over this territory. The beds remaining are thought to belong mostly to the Lower Coal Measures. The only fossils found are a few fragments of plants. No satisfactory columnar section has been obtained of the beds, but their thickness cannot be less than four or five thousand feet.

*Period of Folding.*—At the end of the Carboniferous age, or possibly before it, the beds of sediment in southwestern Arkansas and the adjacent portion of the Indian Territory began to yield to an apparently horizontal pressure. Gradually the great Ouachita uplift rose, and the upper beds began to fold. This continued until the upper beds were folded closely and frequently even overthrown; in fact, in this area the overthrown folds or overturns are the most common kind of fold, and testify to the intensity of the folding action.

This folding took place very slowly, so slowly that erosion may have almost kept pace with the uplifting beds. Besides the two kinds of anticlines, the normal anticline and the overturned anticline, the region is full of faults and crushed and broken structure;

so that, with the scarcity of outcrops, it is impossible to follow or trace the anticlines with accuracy, though in many cases, by means of their effect upon the topography, they may be followed with some degree of accuracy for long distances.

These folds have a nearly east and west trend, and are crossed in traversing the region in a north and south line.

On one such line there are as many as thirty-nine anticlines in a distance of twenty-four miles. Many of these anticlines cannot be found at more than one place, others may be traced for a score or two of miles. Normal anticlines sometimes merge into overturns.

*A Period of Erosion and Sinking.*—As already suggested, the erosion during the period of active folding may have been considerable; so that it is probable that at no time did the elevations over the area at all approach the altitude that a restoration of the eroded strata would make. At last the time came when erosion exceeded elevation and probably sinking took place over the whole region. This resulted in the formation of a base level of erosion.[1] That is, the land level in its lowest part was so near sea level that subaërial erosion was entirely expended in wearing down the elevations, and as the sinking proceeded and the oceanic waters advanced, wave action completed the leveling process. Evidences of this old sea bottom are abundant; only the narrow remnant of flat country fringing the south edge of the area need be mentioned here.

The exact extent of this inundation is unknown, but there are reasons for believing that it extended north of the region under consideration.[2] During this inundation the Cretaceous beds, of which a remnant is still found lying unconformably on the southern edge of the region, were laid down.

All details of the record of events during Cretaceous times are lost in the region to be studied, the evidence only permitting us to say, that some time previous to the Cretaceous the area was reduced to a base level, after which the Cretaceous beds were laid down. The region may have subsequently been subjected to several periods of erosion and deposition.

Following some or all of these periods of deposition came elevation, with the centre of elevation in the neighborhood of the Rich mountain. This, then, became the centre of drainage for southwestern Arkansas and the adjacent part of the Indian Territory, the streams flowing away in every direction over the newly exposed beds of Cretaceous material. A glance at a map of Arkansas and Indian Territory will show that the streams thus started have persisted to the present.

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[1] Dutton, *Tertiary History of the Grand Cañon District*, p. 76.

[2] *Geol. Surv. of Ark.*, An. Rep. for 1890, Vol. iii, p. 220.

After these streams had cut through the overlying Cretaceous they struck the hard layers of Carboniferous sandstone, and slowly cut their channels down through the harder layers standing across their path. In the course of time the Cretaceous beds were completely removed from the region north of the existing Cretaceous border. The period ends with the deposit of Tertiary beds over the eastern end.[1]

*A Recent Subsidence.*—There has been a recent subsidence of the region which probably did not submerge the novaculite mountains to the north, but brought them in range of wave action. The hard novaculites tend to disintegrate into blocks rather than fine material, and as the waters receded, these blocks of novaculite with others of sandstone were rounded by wave action, broken up and the whole scattered as a great gravel bed, in places at least one hundred and fifty feet deep and probably much more, over the area and far to the south. This subsidence is thought to have taken place in post-Tertiary time. The greater portion of the novaculite and sandstone drift laid down in the preceding period has been removed recently, leaving only a narrow strip undisturbed on the southern edge, and in patches all over the region, where the larger boulders have resisted erosion.

## III. ORIGINAL STRATIGRAPHY.

In this chapter will be considered the character, thickness and manner of deposition of the Paleozoic beds. It will be practically a consideration of the first period in the history of the region, as outlined in the preceding chapter.

### *Petrology.*

*Rocks of the Novaculite Series.*[2]—The divisions of the rocks of the novaculite series made by Mr. Griswold will be followed. These rocks he divides as follows:

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[1] *Geol. Surv. of Ark.*, An. Rep. for 1892, Vol. ii.

[2] *Geol. Surv. of Ark.*, An. Rep. for 1890, Vol. iii, p. 122.

I. Ouachita stones: those novaculites which "originally contained a large percentage of lime."

II. True novaculites: these are the characteristic rocks of the mountains of the Ouachita system. They are believed by Mr. Griswold to be mechanical sediments. They are nearly pure silica, though "originally containing a small percentage of lime." In color they are white, black, red, yellow, gray and mottled.

III. Silicious shales, containing "little lime, but with more abundant clay."

IV. Sandstones and quartzites.

V. Chert.

The finding of a large number of species of graptolites in the silicious shales has shown that the novaculites are of Lower Silurian age and probably belong to the lower part of the Trenton.

### *Petrology of the Carboniferous Area.*

*Sandstones.*—Probably nine-tenths of the Carboniferous beds are sandstones. Mr. Griswold has described a microscopic slide of sandstone from Grindstone Ridge in 6 S., 20 W., which gives the characteristics of a typical sandstone of the region.[1]

"This stone is coarse grained, light gray in color." It contains only a small amount of "iron and earthy material."

"There are rounded as well as angular quartz grains, and a few grains of decomposed feldspar are present. The quartz grains appear to have been eroded against and even into one another; many of them exhibit lines or striations, which probably result from pressure. Since these lines are not continuous from one pebble to another, and have apparently no relation to each other, they must have been produced in some manner on the original grain and in the original rock. Some of the quartz grains show secondary silica added to the original grain to form crystal faces as described by Irving in his article on quartzites.[2] One quartz fragment is filled with very fine needles which may be rutile."

The specimen is a trifle finer grained than the average sandstone. The sandstones naturally grade into each other, but certain artificial divisions may be made for convenience. These rocks have not been, as a rule, identified with any definite position in the strata.

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[1] *Geol. Surv. of Ark.*, An. Rep. for 1890, Vol. iii, p. 141.

[2] *Fifth Annual Report of the United States Geological Survey*, pp. 221–223.

(*a*) The sandstone most commonly met with is a soft, olive green sandstone, upon exposure decomposing rapidly into sand. Except when freshly exposed this rock is seldom seen in its massive state; but its soft edges are constantly found in the roads and over the more level territory. Probably this sandstone differs from the next only in lacking iron.

(*b*) The bulk of exposures of a massive character are of a ferruginous sandstone, usually a dark red or brown. In this, exposure to the air oxidizes the iron, which forms a cement and makes the exterior much more impervious. Frequently the brown color penetrates only a short distance, and the interior is a steel gray or light green in color.

(*c*) In a few localities a very white sandstone was found. Surface exposures are usually quite soft. Where fresh, as was found in digging a well on the farm of Mr. Tom Hodges in 6 S., 19 W., section 4, it is exceedingly tough, making digging very slow and laborious. A few months' exposure of the rock is sufficient to render it very friable and mealy. In places it shows slight traces of pyrite.

(*d*) Of frequent occurrence are varieties of finely laminated sandstones verging into shaly sandstones or arenaceous shales. These are usually dark colored or black, and, where the layers are not too thin, are said to make good stones for chimneys and fireplaces. They often occur in layers not more than a quarter of an inch thick, and are frequently found interbedded with shale. There are many intermediate forms, and varieties differing both in hardness and color, but they are not worthy of special mention.

*Shales.*—The presence of the shales is usually indicated only by the topography or by their being struck in digging wells. Single beds are seldom over fifty feet thick, though in a few places it has a thickness of from one hundred to three hundred feet, and in one place on the Cossatot, in 6 S., 30 W., section 19, it appears to have a thickness of six hundred feet. In one place a thickness of twenty feet was seen to thin out within two hundred to three hundred yards.

It varies in lithographic characters very like the shale of other regions; sometimes it breaks up upon exposure into long, slender, needle-like fragments; sometimes it breaks up into thin laminæ or flakes; at other times it is traversed by joints that cause it to break into angular blocks, and these all weather rapidly into clay. In color they are black, lead colored, cream colored, and reddish.

*Conglomerate.*—First found in the Chalybeate mountain where cut by the Caddo, and later in a large number of places over the region, occurs a coarse grit or fine conglomerate. In places this forms a distinct bed eighteen inches or a few feet thick, but oftener it mingles in indistinct layers with the sandstones in a bed from fifty to one hundred feet in thickness, and varies all the way from a conglomerate to the fine-grained sandstone with which it is associated. It consists of small, rounded grains of milky quartz, none of which are more than a quarter of an inch in diameter, cemented by fine sand and iron.

*Novaculite.*—Reference is here made to a layer of novaculite from two to six inches thick which is found well scattered over the region. Considering the thinness of the layer, its persistence is remarkable, as it was found from range 22 W. to the territory line, and from the novaculite mountains to township 7 S. Unfortunately its exact position in the series could not be determined, but it seems certain that it is above the Silurian novaculite series, yet not separated from that series by more than a few hundred feet. In only one case was it found in a creek section; it usually appears only where the layer is crossed by a road or field. At such places it can be followed by the fragments of novaculite which lie on the surface. In 5 S., 22 and 23 W., it was traced for about six miles, and at other places it wsa traced for shorter distances. It appears to be invariably associated with beds of silicious shales, the whole aggregating a thickness of about fifteen feet. In the centre occurs the characteristic novaculite from two to six inches thick. On either side of the novaculite layer is an exceedingly fine-grained silicious shale with hackly fracture, differing from novaculite in appearance only in that the grain can be made out. From this the transition may be traced through less and less silicious shales, until, at a distance of seven or eight feet on either side, it has entirely given up its silicious character and appears to be a soft, argillaceous shale, crumbling easily in the fingers, its only resemblance now to the neighboring novaculite being its color, as it still retains the peculiar drab and pink which run through the whole series.

*Igneous Rock.*—There appear in many places from Amity westward outcrops of rocks containing white specks a sixteenth of an inch in diameter and smaller. Other unknown ingredients appear in thin sections, but in hand specimens the white specks are a characteristic by which it can be recognized. The rock matrix in which this white material occurs does not appear to be constant. In places it is a hard rock ringing under the hammer, with the white specks sparsely scattered through it; in other places it is a quartzite; in some places the white and yellow specks occur in a matrix of shining black rock; in others in a shaly breccia; but the matrix is generally a light green earthy material.

The proportion of white material varies from a very small per cent. to rocks in which there is little else. In many of the harder beds the soft white material weathers out, giving the rock a very cellular appearance. A typical locality is on the Amity-Hot Springs road a mile north of Amity. It here forms a bed thirty-three feet thick. It appears to be regularly bedded at every exposure found. It is well exposed in front of the Bushy Mill in 4 S., 30 W., section 7, and on the Line road, in 5 S., 32 W., section 1. It is apparently but a short distance above the novaculite series. Williams and Penrose, of the Arkansas Survey,[1] report a similar deposit in north Arkansas, which there occurs on the dividing line between the Silurian and Lower Carboniferous strata. The examinations which they have made microscopically and otherwise have led to the suggestion that this is an ash bed indicating volcanic activity somewhere at the end of the Silurian. The great variation in the matrix rocks would seem to agree with such a theory.[2]

*Novaculite Breccia.*—At the same locality a mile north of Amity on the Amity-Hot Springs road are found many fragments of a novaculite breccia. This is probably the same as the novaculite conglomerate referred to by Mr. Griswold, but in this case it is invariably a breccia, the fragments which here measure from an inch or two in diameter down, presenting no evidence of previous erosion.

The matrix of this breccia is usually a light green sandstone, though in a few instances it is reddish or brown. The fragments which in some cases make up the bulk of the rock, in others only scattered through the sandstone, are of novaculite and vary in color from white to red or black.

*Changes in the Rocks. Sand and Clay.*—The most universal change is the disintegration of the rocks into sand and clay. Possibly related to the sandstone is a white, friable, decomposed sandstone found at a few places. A typical locality is in fields about a mile north of Amity near the Caddo Gap road. It crumbles between the fingers into a white, dust-like powder; when dry it is almost as white as chalk. This soft, decomposed condition extends to such a depth that gullies once started in it, cut deep, cañon-like ditches resembling those so common in the soft Cretaceoul marls of the region to the south.

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[1] *Geol. Surv. of Ark.*, An. Rep. for 1890, Vol. ii, p. 375, and Vol. i, p. 128.

[2] Chemical analyses of the north Arkansas beds here referred to show that they are phosphate rocks. An example of the rock collected by Dr. Ashley was found to contain only nine per cent. of calcium phosphate.—*J. C. Branner.*

In this sand are great numbers of concretionary ironstones, from the size of the fist up to three or four feet in diameter. These are strewn over the surface, or protrude from banks, or occasionally may be observed capping a short column of the surrounding soft material. They are usually dark brown and consist of several layers averaging half an inch thick in which the proportion of iron is quite large, surrounding a kernel of exceedingly tough gray sandstone.

Beside the ironstones, this sand is found in some places intersected by numerous joint-planes filled with thin films of iron. Quartz veins and crystals are especially abundant in localities of this nature. Through the sand are frequently little nodules of silicious shale invariably incrusted with a soft, yellow layer. These iron incrustations are formed by waters dissolving out the iron and other impurities which are again deposited in the numerous joint planes; the quartz is deposited at the same time. Quartz filling the crevices in the sandstone is abundant over most of the area. While in some places this forms only a film just thick enough to give a sparkling appearance to the rock when broken open, in others it occurs as solid veins a foot or more in thickness, which may withstand weathering better than the enclosing rocks and may appear as a low wall across the country. The smaller veins, as a rule, intersect the bedding planes at right angles or at a high angle; but many of the larger ones run parallel to the strike. There is such a case in 7 S., 32 W., sections 8 and 9, on Robinson's Fork of the Rolling Fork of Little river, where a protruding vein of quartz can be traced a mile or more in the line of strike.

Masses of interlocking crystals occur frequently, and occasionally well-formed single crystals are found. In many places in the western part of the region, the ground is completely covered with fragments of quartz, as on the "line road" in 5 S., 32 W., section 25, where the road is paved with quartz for nearly half a mile.

### *Superposition of the Beds.*

Mr. Griswold divides the Silurian strata into two series; the novaculite series, and the beds below the novaculites. The beds below the novaculites he estimates to be 1300 feet in thickness, as far down as exposed. They consist of gray, black and yellow shales at the bottom, cherty blue limestones next above, then massive quartzose sandstones, limestones, and shales.

From several columnar sections the novaculite series appears to vary greatly in different localities. He gives, however, a generalized section, in which the order from the bottom upward is: Silicious shales, 200 feet; shale, 300 feet; novaculite, 250 feet; shale, 100 feet; novaculite, 100 feet; novaculite with silicious shale at bottom, 250 feet; novaculite breccia or conglomerate, a thin layer.

The variation in these layers may be judged by an examination of Mr. Griswold's sections.[1] Thus, as an example, the upper layer of novaculite in the Boss Allen Creek section is 500 feet thick, while in the South Fork of the Caddo section it is only 60 feet thick.

*Stratification of the Carboniferous Beds.*—No satisfactory columnar sections of the Carboniferous beds were obtained.

Outside of the immediate channels or banks of streams, rock exposures are rare, and when found are seldom extensive enough to give more than the dip, and the rock exposures in the stream are not usually more than a few yards long. Now and then a continuous exposure is found for several hundred feet, and in a few cases longer exposures are found; but usually between the long exposures there are so many stretches concealed, in which may be folds, or faults, or other unknown factors, that one cannot be sure of the structure. Had the beds been such as to permit identification and correlation, doubtless satisfactory sections could have been made. On Plate I are given the best general sections obtained.

*Plate I, Section I.*—This section was obtained on the Rolling Fork of the Little river. In 8 S., 32 W., the lower part of section 11, is a perpendicular bluff on the east bank of the Rolling Fork known as the "Buzzards' Roost." The dip at this point is about 12°, S. 18° E. Continuing up stream, sandstone is met with in bluffs and in the stream bottom almost continuously, dipping from

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[1] *Geol. Surv. of Ark.*, An. Rep. for 1890, Vol. iii, Pl. iii.

10° to 15°, until shales are met with in the flats at the Bellah mine. Only one important break occurs, where the valley of Rabbit creek comes in. At this point may be a heavy bed of shale, and shale may exist at other points along the section, but was not seen.

From 1500 to 2000 feet of sandstone are omitted from the top of this section. The existence of faults is quite possible, but no evidence of any was found.

The position in which this section is placed relatively to the others is based upon the occurrence, in the strike of these shales and six miles to the east, of the thin beds of novaculites and shales which are known to be not far above the principal bed of novaculite.

*Section II.*—Section ii shows the order of rocks on Cossatot river at the gap near Pontiac post-office. The ridge crossing the Cossatot just north of Pontiac has black novaculite exposed at the centre of an anticline. The section starts from the exposure of novaculite in the gap, and runs south to where the river turns northwest half a mile below. The sandstone overlying the novaculite is poorly exposed on the south side of the anticline, but shows on the north side, and also on the south side of the ridge, east of the river. A careful section was made at this place, but as the shales and sandstones at many points in it are crushed together and broken, suggesting faults, the section is not altogether trustworthy. Omitting minor details the section is as follows:

| | FEET. |
|---|---|
| Sandstone | 150 |
| Concealed | 150 |
| Heavily bedded sandstone with thin beds of shale | 375 |
| Shale with occasional beds of sandstone | 325 |
| Concealed | 225 |
| Shale and sandstone much crushed | 175 |
| Sandstone in thin beds | 175 |
| Shale and sandstone layers | 50 |
| Sandstone | 25 |
| Sandstone and quartzite | 350± |
| Black novaculite | base |
| Total | 2000 |

*Plate I.*

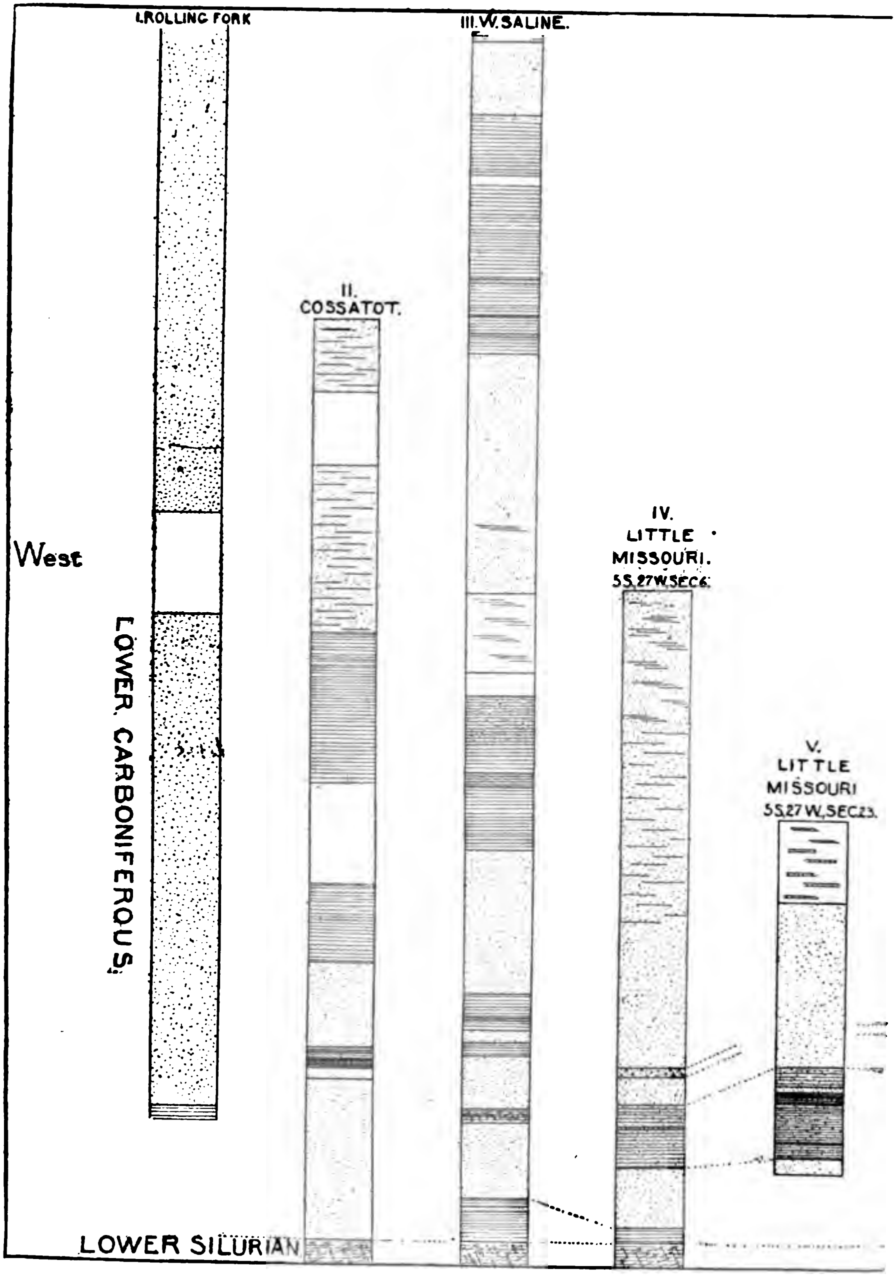
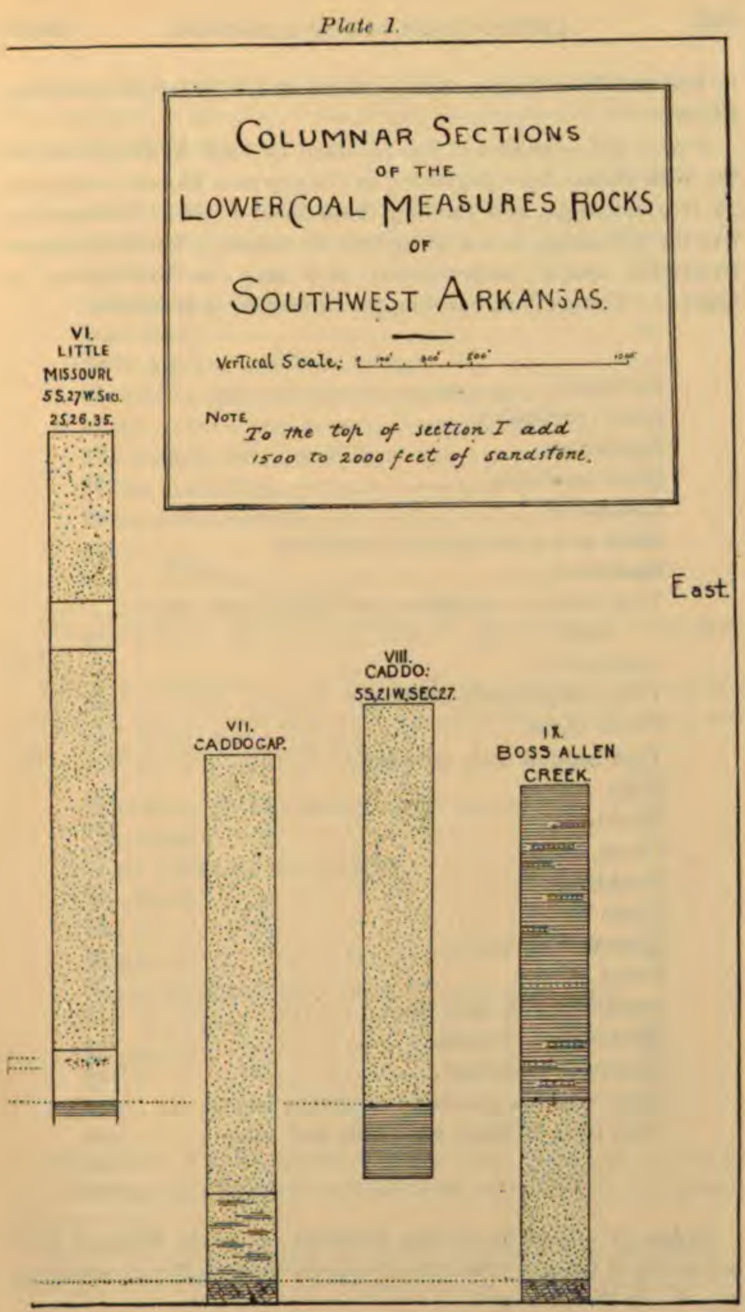

I.ROLLING FORK
III.W.SALINE.
II. COSSATOT.
IV. LITTLE MISSOURI. 5S.27W.SEC6.
V. LITTLE MISSOURI 5S.27 W.SEC23.
West
LOWER. CARBONIFEROUS.
LOWER SILURIAN

Plate 1.



COLUMNAR SECTIONS
OF THE
LOWER COAL MEASURES ROCKS
OF
SOUTHWEST ARKANSAS.

Vertical Scale;

NOTE To the top of section I add 1500 to 2000 feet of sandstone.

This section is broken at its southern end by a fault of unknown throw.

*Section III.*—Section iii was recorded by Prof. A. H. Purdue on the West Saline river, beginning at the gap near Moore's mill, 4 S., 28 W., section 31, and running south about a mile. This section, like the preceding, is not altogether trustworthy, for the strata are frequently nearly perpendicular and may be overthrown or faulted. The section, omitting minor details, is as follows:

| | FEET. |
|---|---|
| Sandstone | 10 |
| Shale (probably) | 75 |
| Sandstone | 165 |
| Shale (probably) | 165 |
| Concealed | 20 |
| Shale with a few layers of sandstone | 375 |
| Sandstone | 530 |
| Thin bedded sandstones and shales (poor exposure) | 175 |
| Concealed | 50 |
| Thin bedded shaly sandstone | 100 |
| Green shale | 50 |
| Thin bedded shaly sandstone | 30 |
| Shale | 135 |
| Sandstone | 320 |
| Green shale | 70 |
| Sandstone | 10 |
| Green shale | 25 |
| Quartzose sandstone | 35 |
| Green shale | 30 |
| Sandstone with some shale | 115 |
| Novaculite and shale | 45 |
| Quartzose sandstone | 115 |
| Shale with few quartzitic sandstone layers | 100 |
| Thin beds of black novaculite and shale | 400 |
| Total | 3195 |

*Section IV.*—Section iv was observed on Little Missouri river beginning at the gap where the river cuts through Prairie mountain in 5 S., 27 W., section 6.

The anticline at this gap shows nicely; the section as given on Pl. i begins with the top of the black novaculite and shale. The section is as follows:

| | FEET. |
|---|---|
| Sandstone with some shale (poor exposure) | 300 |
| Sandstone with thin layers of shale | 400 |
| Sandstone | 365 |
| Grit or conglomerate | 25 |
| Sandstone | 60 |
| Shaly sandstone in thin layers | 140 |
| Sandstone, soft yellow where weathered | 130 |
| Shale | 30 |
| Black novaculite and shale | 400 |
| White novaculite | 400 |
| Shale and sandstone | base |
| Total | 2450 |

The thickness of the Carboniferous in this section is about 1600 feet.

*Section V.*—Section v is on Little Missouri river, in 5 S., 27 W., section 23, on the north and south stretch in the middle of the section. The section obtained was:

| | FEET. |
|---|---|
| Sandstone, all that showed (poor exposure) | 185 |
| Sandstone | 370 |
| Shaly sandstone thin bedded | 40 |
| Sandstone | 10 |
| Shale | 15 |
| Sandstone | 5 |
| Shaly sandstone thin bedded, with some hard sandstone | 130 |
| Sandstone | 30 |
| Total | 785 |

This section is well exposed along the river bank, and is accurate as far as it goes. The dip at the north end is high, but quickly becomes low.

*Section VI.*—Section vi is on Little Missouri river, beginning at Pine mountain, in 5 S., 27 W., section 26, and running south to where the river turns east and northeast. The dip is low, from 10° to 20°. At the north foot of Pine mountain a bed of shale is exposed, then for a short distance it is concealed beneath broken sandstone blocks. Near the top of the mountain on the north side in this area of no outcrops were found many pieces of grit or conglomerate, indicating its presence there in place. Massive layers of sandstone, twenty to forty feet thick, form the top and south slope, dipping 20° south. For most of the rest of the distance the sandstone is exposed almost continuously in low, perpendicular cliffs, the dip being very low. This is thought to be a single outcrop to the centre of section 31 in the next township east. This cross-section and the preceding are separated only by a short stretch in which there are no exposures. The dip is the same, and it is possible that the two are part of one section; many things, however, point to its being a repetition of the preceding section, and the topography also is suggestive of a fault between the two.

The section gives:

| | FEET. |
|---|---|
| Sandstone | 400 |
| Concealed | 100 |
| Sandstone | 900 |
| Concealed | 115 |
| Shale | 30 |
| Total | 1545 |

*Section VII.*—Section vii, at Caddo Gap, is quoted from Mr. Griswold.[1]

It is as follows:

| | FEET. |
|---|---|
| Sandstone | 980 |
| Sandstone with some shale | 200 |
| Silurian novaculites, etc | base |
| Thickness of the Carboniferous beds | 1180 |

*Section VIII.*—Section viii is on Caddo river, in 5 S., 21 W., section 27. A long stretch of low dip (from 5° to 10°) with continuous outcrops gives this section:

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[1] *Geol. Surv. of Ark.*, An. Rep. for 1890, Vol. iii, Pl. iii.

| | FEET. |
|---|---|
| Sandstone | 900 |
| Shale | 75 |
| Black shale with fossils | 100 |
| Total | 1175 |

There is evidence of much shale below the bottom of this section.

*Section IX.*—Section ix is on Boss Allen creek, in 3 S., 18 W.; it was obtained by Mr. Griswold.[1]

| | FEET. |
|---|---|
| Shale with some sandstone | 700 |
| Sandstone | 400 |
| Novaculites, etc. (Silurian) | |
| Thickness of the Carboniferous | 1100 |

Besides these sections, mention might be made of a continuous outcrop of perpendicular sandstone with some thin layers of shale, which forms the east bank of the Little Missouri in 6 S., 26 W., section 25. In this outcrop the beds exposed have apparently a thickness of 1500 feet.

On the Cossatot, in 6 S., 30 W., section 19, is a continuous exposure of arenaceous shale or shaly sandstone giving a thickness of 600 feet, which is much greater than the exposure of the same rock elsewhere.

On the Cossatot, in 5 S., 30 W., section 17, is a fine exposure of sandstone which at this point crosses the river in high massive ledges from ten to twenty feet thick and dipping north 30°. The river cuts through these ledges forming a series of cascades known as the Falls of the Cossatot. The thickness is about 800 feet.

### *Stratigraphic Position of the Beds.*

(*a*) *The Novaculite Breccia.*—The novaculite breccia was only met with in quantity a mile north of Amity (see p. 232). It appears there following the strike of the rocks. Mr. Griswold reports[2] a novaculite conglomerate or breccia occurring just at the top of the novaculite series. This is thought by Dr. Branner to be the top of the lower Silurian strata.

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[1] *Geol. Surv. of Ark.*, An. Rep. for 1890, Vol. iii, Pl. iii.

[2] *Geol. Surv. of Ark.*, An. Rep. for 1890, Vol. ii, p. 300.

(*b*) *Igneous Rock.*—This is well shown at the same locality as the breccia, and there appears to occupy about the same horizon. It was found at about a score of places west of the Cossatot, these being always, where the structure was known, just at the axes of anticlines; and, as in many places among the novaculite mountains, it is found very close to the novaculite, it may be safely assumed that it is but a short distance above the novaculite, and may well be taken, as has been suggested, as the dividing line between the Silurian and the Carboniferous.[1]

(*c*) *The Thin Bed of Novaculite and Associated Shales.*—Notwithstanding the large number of places at which this bed was met with, it only appears in one of the columnar sections. In the Saline section it appears not much more than one hundred and fifty feet above the top of the black novaculite and shales. It is usually exposed near anticlines; in many cases, exposures are found on each side of the anticline. This would place it low in the series, but the distance between the exposures, frequently a quarter of a mile, and the distance of exposures from the thick-bedded novaculite, where exposed in the fold over a novaculite ridge, suggest that generally this thin layer of novaculite is several hundred feet above the black novaculite. Considering the thickness of the bed, from three to ten inches, it is remarkably persistent; the most southern exposures in township 7 S. appearing practically identical in thickness and character with the exposures close to the novaculite ridges.

In the Saline section it is in a thick bed of sandstone. In a fine exposure on the Caddo in 5 S., 23 W., section 21, northwest corner, there are thick beds of shale above and below it, and it shows this difference in many exposures.

Whether or not it is above or below the lowest of the beds which, by their fossils, are known to be Carboniferous, is not known. If it is below and belongs to the Silurian novaculites, we must acknowledge the existence of belts of Silurian strata all through the area. If it is above, as seems possible, we have the remarkable case of unusual conditions which dominate in one age returning after a long interval in a much later age, not in a single locality, but widespread though of short duration.

(*d*) *The Grit or Fine Conglomerate.*—In Pl. i, Sec. iv, on the

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[1] *Geol. Surv. of Ark.*, An. Rep. for 1890, Vol. i, p. 128, and Vol. ii, p. 375. For doubt regarding the igneous nature of some of these beds see footnote on p. 232.

Little Missouri, the grit appears about four hundred feet above the black novaculite. In the Cossatot section it appears east of the river just below the shales and not more than six hundred feet above the black novaculite. This, together with the fact that it is usually found elsewhere close to the anticlines, indicate that it is not far above the novaculite, probably within a few hundred feet. Its relation to surrounding beds varies greatly: in places it is just below thick beds of shale, in other places it is just below thick beds of sandstone; hardly any two exposures agreeing, so that while lithologically it is very similar wherever found, it is quite possible that the different exposures are only local in extent and occur in different horizons. In several places, however, the grit has been traced in more or less continuous exposures for several miles.

*A General Section.*—Could we construct a general section it would be somewhat as follows:

5. Sandstones forming top of exposed beds and having a thickness at one place of four thousand feet or more.

4. A variable set of beds of shale and sandstone measuring at least several hundred feet in which occur,

(*a*) A bed of beds or grit.

(*b*) A thin bed of novaculite and silicious shales.

3. A bed probably of igneous origin, thirty-three feet.

2. A thin bed of novaculite breccia.

1. Silurian novaculites, shales and sandstones.

## IV. Fossils and Age of the Strata.

*Caddo River Locality.*—The first and most promising locality at which plant remains were found is in 5 S., 21 W., on the tongue of land just east of the mouth of Point Cedar creek. There is here a good exposure of black, carbonaceous shale having a peculiar hackley fracture. This contains a great many minute fragments of plants. Only a few are large enough to show any characters; of these the most common are long stems showing no branches, but ribbed longitudinally. These stems average a quarter of an inch in width by several inches in length. They are the most common fossils found in the area. They occur at several places, but at none of these places were any obtained which would permit a closer identification than that they were the stems of some plant. There was also found at this point a fragment of a larger stem showing leaf scars. The original material of the specimen has been carbonized. The specimen was not identified. Small round stems are also found at this place, but though showing some structure under the microscope, they were not identified. This and the next were the only localities found which promise fossils of value on further exploration.

*Bluff Mountain Locality.*—Sparsely scattered through the shale and sandstones forming the northern part of the bluff on the west side of Antoine creek at Bluff mountain in 7 S., 23 W., section 34, were found many fragments of stems similar to those mentioned above.

*Suck Creek Locality.*—The same kind of stems were also found in a loose block, well up on the north bank of Suck creek in 7 S., 23 W., section 30, at the bend where the creek changes from an east to a south course.

*Chalybeate Mountain Locality.*—Where the Caddo Gap road crosses the Chalybeate mountain in 7 S., 24 W., section 1, the rocks exposed in working the road near the top show traces of plant life, but nothing was found that could be identified.

*Little Missouri Locality near Murfreesboro.*—On the Little Missouri river in 8 S., 25 W., section 6, a few of the stems common to this region were found in an argillaceous sandstone.

*Little Missouri Locality near Pine Mountain.*—Plant fragments like those mentioned above were also found on the Little Missouri in 5 S., 27 W., section 23, in the shales in the bend of the river half a mile north of where Pine mountain strikes the river.

*Little Missouri Locality near Gap.*—A short distance south of the Gap in 5 S., 27 W., section 5, at the south end of the layers of shaly sandstone, the shale or sandstone is full of carbonaceous streaks and patches, which prove to be remains of stems of plants very poorly preserved. The impression of a stem with a thorn was found at this point. The stratigraphic position of this locality is shown on Pl. i, Sec. iv, the specimens are from the top of the arenaceous shale just below the grit shown, and only about 300 feet above the black novaculite and shale.

*Star-of-the-West Locality.*—On the south bank of the creek (just south of Star-of-the-West), at the foot of the hill, was found a section of a stem an inch and a half in diameter which is probably a Calamites. This was found loose on the hillside and probably came from the shales which form the bank at this point.

*Panther Bluff Locality.*—At Panther Bluff on the Saline river in 6 S., 29 W., section 33, shales are interbedded with sandstones, and in these shales a fragment showing the peculiar ribbing and jointing of the Calamites was found. This was the only specimen found of which the genus could be determined with certainty.

*Saline River Locality near Antimony Cave.*—Prof. Purdue found fragments of plants on the Saline at the bend just above Arsenic Cave in 7 S., 29 W., section 21. They are too poorly preserved for identification.

### *Animal Remains.*

Some fragments of crinoid stems and a few bryozoans, were found in a loose quartzite boulder near the crossing of Antoine creek by the Old Military road (8 S., 23 W., section 24). The only other evidences of animal life found were what are thought to be tracks of worms or crustaceans. These were found at two localities in 5 S., 23 W., section 31, on the Amity-Kirby road, a quarter of a mile west of the crossing of the North Fork of Antoine creek, and also in section 14, on a knoll southeast of Sugar Loaf mountain.

### *Geologic Age of the Rocks.*

The age of the Silurian strata has been determined by means of the numerous graptolites found in the shales associated with the novaculite. The shales containing these graptolites have been correlated with the Norman's Kill beds of New York, and are referred to the lower portion of the Trenton series.[1] These fossils fix the age of the Silurian beds.

Of the fossils found in the overlying Lower Coal Measures rocks only three have any diagnostic value: the two specimens of Calamites and the stem found on the Caddo, which shows the leaf scars. These plant remains are probably of Carboniferous age. The stems and other fragments often found are of no value, as they might occur anywhere from the Cambrian up, but from their association on the Caddo with the stems believed to be Carboniferous, it has been assumed that they belong to the Carboniferous, and that all beds in this particular region in which they occur are Carboniferous.

Upon the above grounds it has been thought safe to refer the strata above the novaculites to the Carboniferous age. The grits which cap the mountains along the northern face of the Boston mountains gradually dip south and disappear under the heavy beds of the Coal Measures which fill the syncline of the Arkansas river basin. If these beds persist to the south they should appear again on the north side of the Ouachita uplift, and should disappear with a south dip on the south side of the uplift. The State Geologist is of the opinion that the grits described in this area represent the southern extension of the Millstone Grit of north Arkansas. The two are identical in appearance, except that the rocks of the southern area are never as coarse grained as some of that to the north.

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[1] *Geol. Surv. of Ark.*, An. Rep. for 1890, Vol. iii, p. 418, *et seq.*

The Millstone Grits of north Arkansas are at the bottom of the Coal Measures; so that if the grits south of the Ouachita uplift be correlated with those of north Arkansas we must consider that we have strata referable to both the Coal Measures and Lower Carboniferous or Mississippian series.

Without regard to time, it seems highly probable that the strata south of the Ouachita uplift were originally continuous with those just north of it. No direct proof of this has been found, nor has anything been found that conflicts with this theory.

### *Previous Correlations.*

Thomas Nuttall, who was in this part of Arkansas in 1819, published many observations on the geology, but he found no fossils in these lower sandstones and made no attempt to correlate them.[1]

In 1834, G. W. Featherstonhaugh, U. S. Geologist, made an examination of the elevated country between the Missouri and Red rivers.[2]

He passed along the eastern edge of our region and down the Ouachita river. The ferruginous sandstones he referred to the Old Red Sandstone (Devonian) of England, which he thought to rest upon the grauwacke, the grauwacke being the shales and shaly sandstones at the bottom of the series.

He failed to recognize the intimate relation between the shale and sandstone or the folded condition of the strata. He was originally led to this classification, as Marcou[1] and others have been, by finding at Little Rock the highly contorted shales at the "Little Rock" and a few miles above, at "Big Rock," the almost horizontal sandstone strata. In 1842, Dr. W. Byrd Powell[2] questioned Featherstonhaugh's correlation with the grauwacke, but he accepted it as the best that could be given, but included the sandstones in the same classification. Dr. Englemann saw something of the region between Little Rock and Hot Springs, but he found no fossils, and the only suggestion as to correlation was that the sandstone at Little Rock was "most probably analogous to that of Lake Superior."[3]

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[1] "Observations on the Geological Structure of the Valley of the Mississippi," by Thomas Nuttall, *Jour. Acad. Nat. Sci. of Philadelphia*, Vol. ii, Pt. i. Phila., 1821, pp. 48–52.

[2] *Geological Report on an Examination made in 1834 of the Elevated Country between the Missouri and Red Rivers*, by G. W. Featherstonhaugh, Washington, 1835, p. 71.

Owen refers this region to the Millstone Grit,[4] including in the same formation the novaculites, which we now know to be Silurian.

He concludes that these beds have an immense thickness from observing sections many miles long, where the beds appear to dip steadily in one direction. This has since been shown to be due to a number of consecutive overturns.

*Subsequent Observers.*—Since the beginning of the present survey, several of its members have crossed this region. No fossils were found, and so, though Mr. Branner provisionally referred these beds to the Lower Carboniferous,[5] he thought it better to speak of them simply as Paleozoic.

### *Extent of Beds.*

It can be assumed with some degree of certainty that the strata exposed over the area under discussion are continuous. This refers only to the beds as a whole, not to individual layers.

The extent to the south and east can only be conjectured, but as no thinning out could be detected, the strata may have had a considerable extent in those directions.

As will be discussed later, it has been suggested that the Ouachita uplift is a remnant of a westward extension of the Appalachian chain. As this view presents certain difficulties, there has also been advanced the theory that that westward extension, if it existed, was to the south, possibly crossing the northern part of Louisiana. In such a case these beds may have been continuous with, though varying from, the Carboniferous exposures on the west of the Appalachians.

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[1] *Exploration and Survey for a Railroad from the Mississippi River to the Pacific Ocean,* Vol. iii, Pt. iv, p. 122.

[2] *A Geological Report upon the Fourche Cove and its Immediate Vicinity,* by W. Byrd Powell, M.D., Little Rock, 1842.

[3] *Proc. A. A. A. S.,* v, 1851, p. 199.

[4] *Second Report of a Geological Reconnoissance of the Middle and Southern Counties of Arkansas,* made during the years 1859–61, by D. D. Owen, Philadelphia, 1860, pp. 32, 33, 95, 110, 124.

[5] *Geol. Surv. of Ark.,* An. Rep. for 1888, Vol. ii, p. 262.

To the west the same beds run into the Indian Territory, and the Carboniferous is found as far west as the 100th meridian and in Texas as far south as the thirty-first parallel.

To the north the strata are thought to have been originally continuous with the strata just north of the Ouachita uplift.

Several attempts to prove this continuity were made, but without much success, though nothing to the contrary was found.

### *Direction and Conditions of Depositions.*

Mr. Griswold, from his study of the novaculite area, came to the conclusion that the sediments with which he had to deal came from the south.[1] This was largely based upon the fact that the sandstones overlying the novaculite on the south are largely represented on the north by shales. Apparently the same fact is also to be observed in our area. This is shown by the difference in the topography: almost no shale being met with in the southern part of the region, and east and west valleys of any breadth are uncommon, while as the novaculite mountains are approached there are broad valleys with frequent exposures of shale. It was at first thought that this might be due to the strata as a whole having a slight south dip, so that the shales, which are low in the series, were not as fully exposed, but, as will be shown later, the proof is to the contrary. There also appears to be more shale exposed over the eastern part than over the western; but this is not marked enough to make one feel sure but that greater erosion may have had something to do with the difference.

## V. General View of Structure After Folding.

In Fig. 1 is given a generalized section across the State in a north-south line through range 30 W.

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[1] *Geol. Survey of Ark.*, Rep. for 1890, Vol. iii, p. 193.

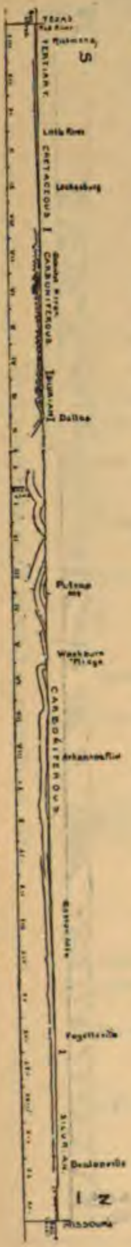

FIG. 1.—North-south section across the State of Arkansas through range 30 W.

This section has been compiled from observations by members of the survey.[1]

It shows a monocline on the north, a syncline in the centre, an anticline south of that, and a nonconformity at the southern limit.

The gradual change from practically horizontal strata on the north to highly folded on the south is also shown.

At the north Silurian strata are exposed, but on going south these gradually sink beneath Carboniferous deposits, to appear again in the great anticline of the Ouachita uplift. On disappearing again they continue but a short distance below the surface, until they and the overlying Carboniferous beds are covered by the gently dipping Cretaceous strata.

The section is given to show the relation of the area under discussion to the general section of western Arkansas. The line on which the section is made crosses the Ouachita uplift not far from its western nose, so that the Silurian outcrop is very small compared with what it would be on a north-south line further east, and likewise the Carboniferous outcrop south of the Silurian would be narrower in a section further east.

### *Historical.*

None of the early writers on the geology of Arkansas seem to have made any attempt to work out the structure of the Ouachita uplift, or of the region immediately south of it.

*Comstock.*[2]—The first attempt to give system to the folds was made by Dr. Theo. B. Comstock

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[1] Winslow, "Geotectonic and Physiographic Geology of Western Arkansas," *Bulletin Geological Society of America*, Vol. ii, pp. 225–242, Fig. 1; *Geol. Surv. of Ark.*, Rep. for 1891, Vol. iv, sections; *Geol. Surv. of Ark.*, Rep. for 1890, Vol. iii, section on Mt. Ida sheet; *Geol. Surv. of Ark.*, Rep. for 1888, Vol. ii, sections p. 126.

[2] *Geol. Surv. of Ark.*, Rep. for 1888, Vol. i, pp. 130–166.

North-South Sections in the Paleozoic Region South of the Novaculite Area.

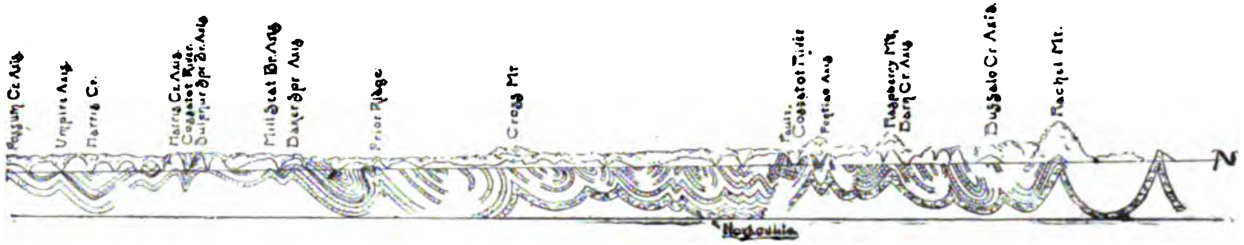


FIG. 1.—Section on Antoine Creek.

Horizontal scale: 1 inch = 2 miles. Vertical scale: 1 inch = 3000 feet.

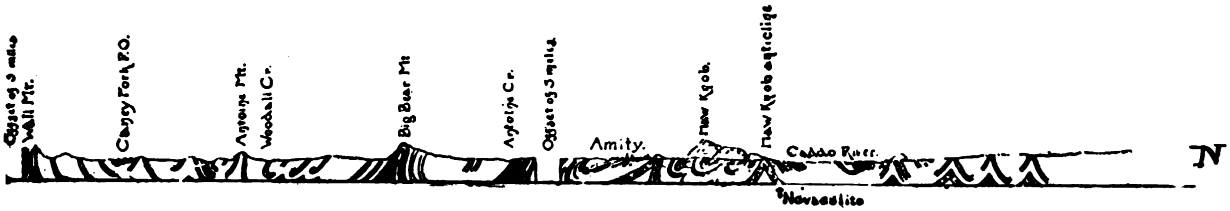


FIG. 2.—Section on Cossatot River and Brushy Fork.

*Plate II.*

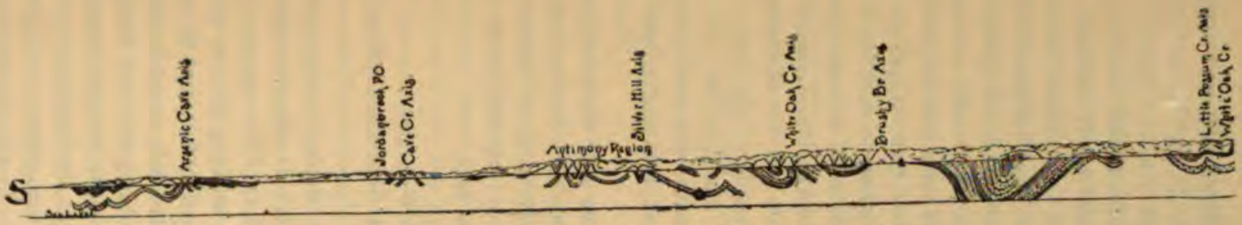


FIG. 1.—Section on Antoine Creek (continued).

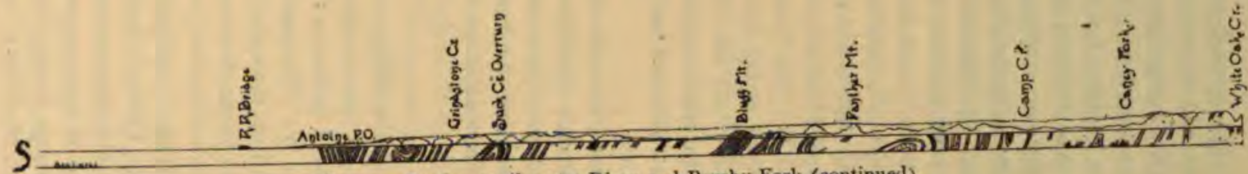


FIG. 2 —Section on Cossatot River and Brushy Fork (continued).

in 1887. He worked only in the western part and mapped out twenty folds and faults having a strike of N. 63° E., and connected with a similar number near Hot Springs.

That he should have found a uniform strike of N. 63° E. is difficult to explain, for the strike is extremely variable, seldom being the same in strata 100 yards apart. At most of the localities cited by him the strike lacks from 10° to 40° of being N. 63° E. The fact that so many ridges run "transverse to all geologic structural lines," he disposes of by introducing "some very powerful cause of greater moment than the twenty folds and faults which cut across the tract." But as a matter of fact these ridges are strictly conformable to the structure. The evidences of faulting which he found are all referable to the simple effects of erosion upon tilted beds, some of which are much harder than others. Considering the shortness of the time spent in the region and the obscurity of the structure, even at the best, and that outside of the river channels good exposures are rare and generally unsatisfactory, and that in the first of his field work, where the structure was more evident, the ridges have a trend of northeast-southwest, it is readily seen how he fell into error.

*Subsequent Observers.*—From that time until the work herein reported was taken up all the work done was such observations as different members of the survey made in traversing the region. These observations soon disclosed the errors of previous work, but did not reveal the number or closeness of the axes.

## *The Cross Sections.*

An idea of the folding can be gained from the north-south sections on Pl. II (see p. 250).

*The Antoine Section.*—Fig. 1 gives a section through the centre of range 23 W. The part in township 6 S. is offset five miles, to a north-south line through Caney Fork P. O. The section in 7 and 8 S. is made along Antoine creek. Its striking general feature is the prevalence of south dips and overturned folds except at the ends. The first attempt to make this section gave only one doubtful north dip in shale. Further, the closeness of folding does not diminish to the south. The exposures are mostly sandstone, though in many cases the presence of shale can be inferred from the topography. In the segment through Caney Fork P. O. the topography is controlled by the structure, this being almost the only locality in the whole area where distinct anticlinal ridges with synclinal valleys between were found.

*The Cossatot Section.*—Fig. 2, Plate II, gives a section up the Cossatot river to the mouth of Brushy Fork, and thence up Brushy Fork to the north line of 4 S. The dip is north with many overthrows to the south. The southern end is not as closely folded as would be the case further east. The presence of one or more layers of shale or shaly sandstone has assisted materially in determining the structure. The exposures along the Cossatot are more numerous and the structure ascertainable with more certainty than on the Antoine. The novaculite is not exposed except at the extreme northern end of the section; but at many places it cannot be far from the surface, as it comes to the surface but a short distance east in Rachel and Raspberry mountains, and a short distance west in Cross mountain.

### *Direction and General Character of the Folds.*

*Eastern Sheet.*—The structure of the eastern portion of the Lower Coal Measures area is obscure, and, as the map shows, but little understood.

This is due to three causes. Principally the prevalence of overturns; next, the fact that erosion has progressed until the streams are comparatively slow, with banks neither high nor precipitous, thus presenting few fresh exposures of rock; and again, the wide distribution of water-worn material which conceals everything.

From these causes the number of exposures found giving a dip and strike would average less than one to the square mile; in many townships they are as low as one in four to eight square miles. If a complete structural map of the region could be made it would probably show many more folds than are here indicated. At the eastern end of the map the anticlines and synclines all run nearly due west. In range 21 W. they all bend south, running 12° to 15° south of west. The Suck creek anticline and Bell's creek anticline are exceptions to this rule.

West of range 23 the folds in township 4 S. regain their due west course, the folds to the south maintaining the direction of 12° to 15° south of west. Of the anticlines shown, about one-half are overturns. Indications suggesting the existence of many other overturns were found, but they were not well enough marked to warrant their insertion.

*The Western Sheet.*—The western half of the area offered somewhat better facilities for working out the structure, due principally to the existence of four large streams running across the folds from north to south. These streams are rapid, and frequently they cut their way through the ridges in deep, steep-banked gorges for long distances. Rocky cliffs seldom occur, but the shallow creek bottoms afford many exposures of rocks. Between these streams exposures are as scarce as further east.

On the other hand the topography is of much service in suggesting structure. It is through the suggestions thus given by the topography that the connections between the exposures of axes have been worked out.

In townships 3 and 4 S. the strike of the folds is east-west or a little north of west. In 5 S. the strike is nearly always about due east-west. In 6 S. the strike is a little south of west, becoming due west as the Indian Territory line is approached. In 7 S. the slightly south of west strike is maintained.

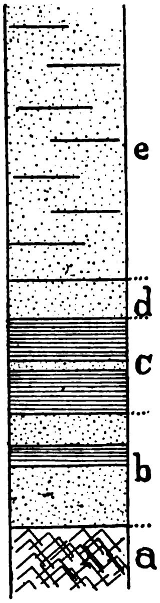


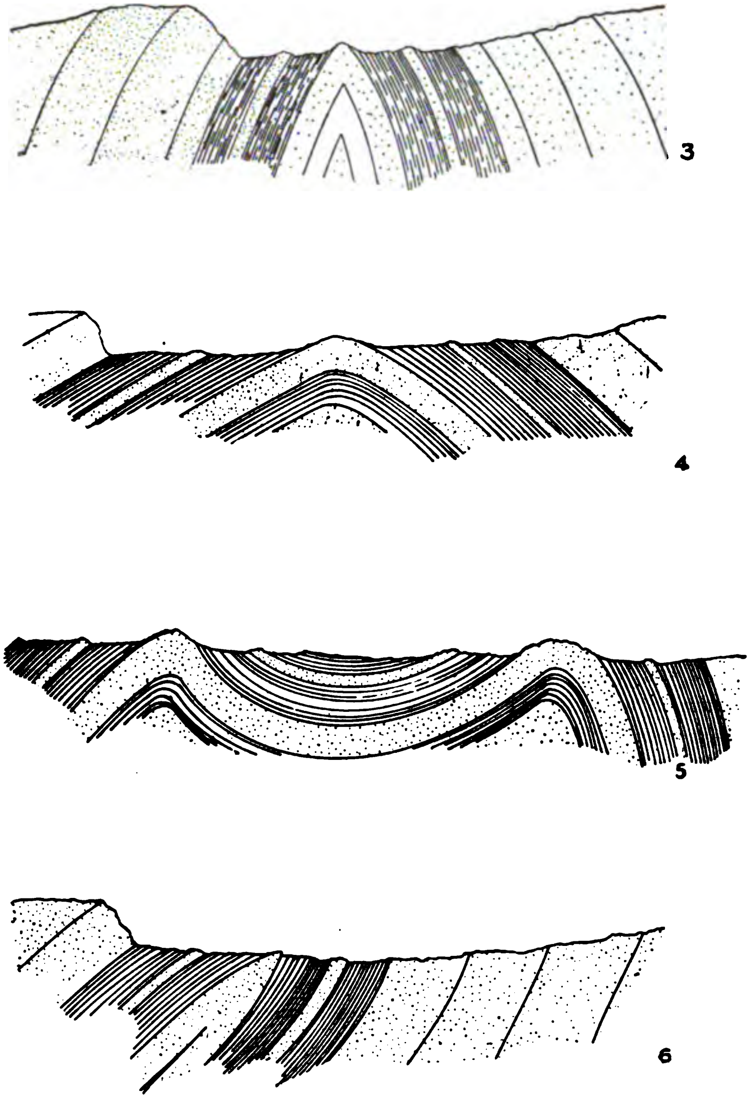
FIG. 2.—Columnar section of Paleozoic rocks south of the Ouachita mountains.

Thus it will be noticed that as the Indian Territory line is approached the fold tends to spread out like a partly opened fan. This results in the folds becoming more open toward the west. While the strata are closely folded or overturned on the Little Missouri and West Saline rivers, on the Cossatot they present more simple anticlines, and still further west, on the Rolling Fork, simple anticlines and lower dips are still more prevalent. This is especially true of the southern half of the region.

Where the dotted lines on the map suggest continuity of the axes, it is not necessarily implied that the anticlines are strictly continuous; as the complete structure, if known, might show two or more anticlines where only one is indicated, and these might be strung along in a line or be slightly out of line with the ends overlapping or running past each other.

## *Structural Types.*

As introductory to tracing out the anticlines and synclines in the next chapter, it may be well to study briefly the effect upon the topography of such a section as here exists, when folded and the much eroded.



FIGS. 3–6.—Sections showing types of structure in the Paleozoic region of southwest Arkansas.

Let Fig. 2 be a very generalized columnar section, in which (*a*) represents the Silurian novaculites, (*b*) the sandstone immediately overlying the novaculites, (*c*) the variable thickness of sandstones and shales, (*d*) massive sandstones, and (*e*) the great thickness of soft and hard sandstones forming most of the section.

The topography developed upon these beds will depend to a great extent upon the character of the folds. In the case of a simple fold, such as are shown on Figs. 3 and 4, where erosion has eaten down until the hard sandstones are exposed, an anticlinal ridge will follow the axis with a valley on either side. Figs. 3 and 4 show the effect of the dip upon the width and character of the valleys. As a rule it is found that, of the ridges formed by the sandstones overlying the shales, the one on the side from which the principal drainage comes is cut down so as not to present an abrupt face. Fig. 5, shows the effect of two such anticlines close together.

Generally one side of the anticline is steeper than the other, as is suggested in Fig. 8, when this becomes overturned the effect is modified slightly, as is shown in Fig. 6.

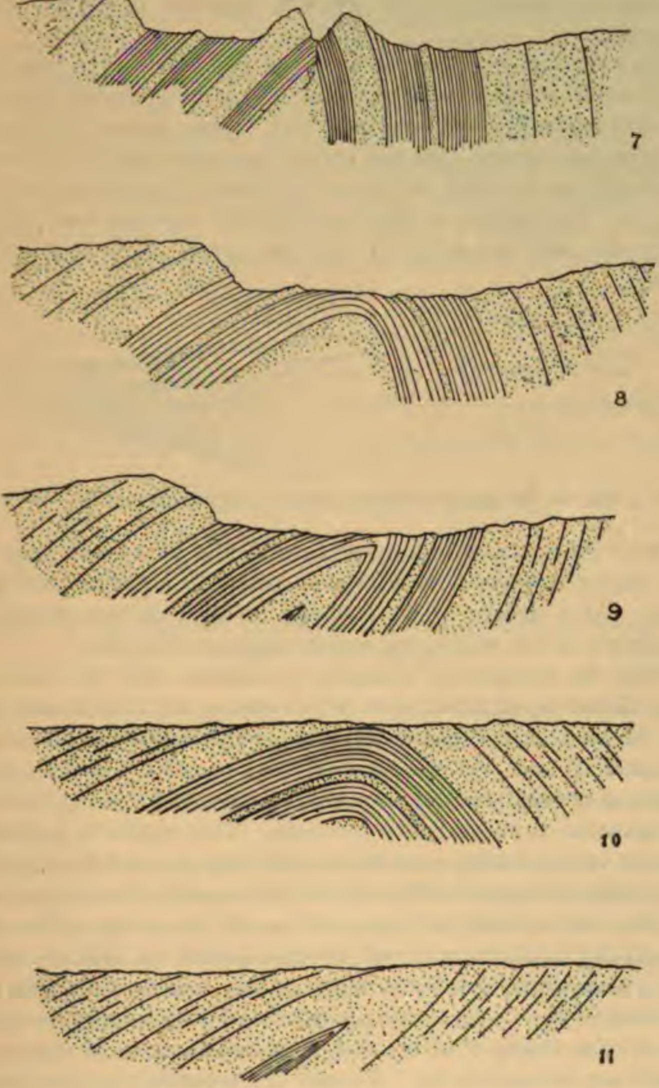
Where shale underlies the sandstone of the anticlinal axis, in time this anticline becomes breached (Fig. 7), and the topography resembles that of which the Wall mountain (Figs. 27 and 28) is an excellent example.

If erosion has not cut down to the underlying sandstone, the result will be the same, except that the anticlinal ridge is omitted and the valley will be narrower, possibly very much narrower. Such an anticline (Fig. 8), is difficult to locate accurately. This is a common type; it is illustrated by the Prairie Bayou anticline (Fig. 16).

Overturns of the kind shown in Fig. 9, are very difficult to recognize; the mere presence of the shaly layers is frequently the only suggestion of their presence. If the shaly layers were as surely located and as completely isolated as in the general section, Fig. 2, this could be relied upon; but, as shown by the columnar sections of Pl. I, it cannot be taken alone as a sure indication.

When the shales of the section are somewhat deeper seated they may not be brought within range of erosion; then the topography gives no clue to the structure. These conditions are illustrated by Fig. 10.

If an overturn occurs under such conditions as those suggested in Fig. 11, unless an exposure is found at the axis, it will generally pass unnoticed.



FIGS. 7–11.—Sections showing types of structure and topography.

In each of these cases, while erosion is the apparent agency, the real determining factor is the comparative elevations of the original surfaces as compared with the average elevations of the surrounding region.

The anticlines may vary in height at different points, however, and a single anticline may represent almost every feature figured; for, as it begins low and gradually rises, it may expose at first only the upper sandstones, then the shales, then anticlinal ridges due to sandstones in or under the shales, as shown diagrammatically in Fig. 12. The anticlines which near the end may have low dips on either side, may be overturned near the centre or for much of its course.

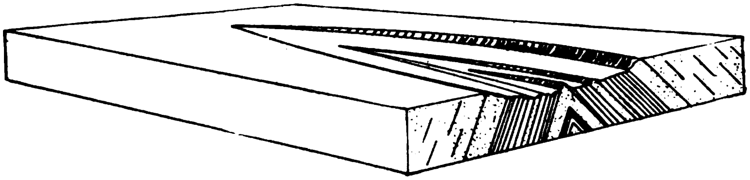
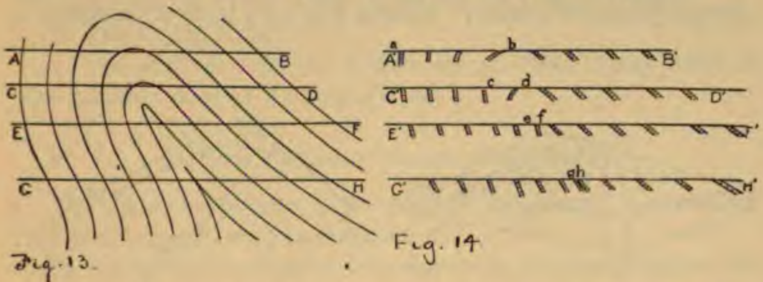


FIG. 12.—Diagram of topography at the end of an anticline.

Under the circumstances represented in Fig. 12 it would seem an easy matter to locate and accurately define the anticlines and synclines. As a matter of fact, almost no such evident structural topography is met with in the region under consideration.

While the topography is largely concordant with the structure, many disturbing elements enter which vitiate any conclusions that may be based upon topography alone. On account of causes to be spoken of later, the main drainage systems of the area are only slightly controlled by structure, their general trend being oblique or transverse to the strike of the folds. This results in a double series of valleys cutting each other at all angles; and through the same causes the main divides are also transverse to the structure and on these for a width of from half a mile to several miles the topography is usually not well enough marked to indicate structure. Many other local and minor causes, such as change in the character of the rocks, faulting, crushing of strata, constant variation in the character of the folds, and others enter as factors to complicate the topography. Though it is probable that the topography, if worked out in detail, would be found to be closely governed by the structure, modified by the factors mentioned, yet, when it is considered that, on account of the density of the forest, it is but rarely that the "lay of the land" can be made out for more than one or two hundred yards from the course pursued, it will be understood why, in a rapid reconnaissance like that undertaken, but little more than suggestions could be obtained from the topography. For these reasons the structure has, in no case, been assumed from the topography alone.

*Overturns.*—Overturns are a common feature of the area. In Fig. 13 is a simple overturn, and on the right side (Fig. 14) are shown the corresponding dips of beds at surfaces of different levels as AB, CD, EF, GH. Thus, in the case of A′B′ the axis is readily recognized; but remembering that no correlation of beds can be made, the section at that point would naturally be interpreted as an anticline at *b* and a syncline at *a*. Such overturns are liable to lead to a confusion which can only be cleared up by careful detailed work.



FIGS. 13, 14.—Diagrams illustrating the structures shown by eroding an overturn to different depths.

In C′D′ and E′F′, the structure is the same, but is somewhat modified.

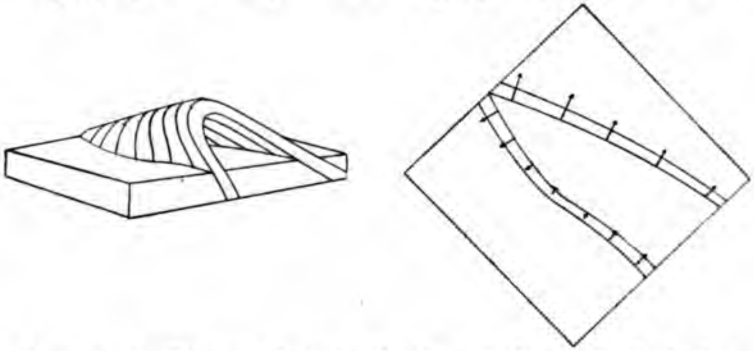
Most of the overturns found have been eroded so as to give exposures between those of C′D′ and E′F′. Sometimes there is a marked change in the dip on the two sides, as a low north dip on the upper side and a high north dip in the underfolded strata.

In such a case an overturn is suggested, and if an exposure giving a dip contrary to the general dip can be found, as *c* in C′D′, it has generally been considered as confirming the probable existence of an overturn at that point.

In many cases the only actual evidence obtainable is a single dip or two contrary to the general direction of dip. In such a case, the suggestion thus given may often be strengthened by the presence of shales, or of the thin bed of novaculite and silicious shale, all of which are believed to be low in the columnar sections and therefore, if exposed at all, would be near the axis. In a few cases the presence of the igneous rock or of parallel outcrops of the thin bedded novaculite and silicious shales was considered as a possible evidence of an anticlinal axis. In only a few cases could the actual continuity of the beds be traced.

When erosion has cut down to the level GH, it is next to impossible to recognize the axis unless a good exposure of rocks low in the series occurs directly in the axis.

When all these fail there has been tried successfully, in cases where the overturn is suspected, the plan of tracing an anticline into the disputed locality. Thus in Fig. 15 a layer of sandstone is represented as rising from a low anticline and merging into a high overturn. Were the block planed off, the outcrop would have some such shape as that shown in Fig. 16, on one side the dip remaining constant in direction, and probably not varying much in amount; on the side toward the observer not only is the outcrop curved somewhat, but the low dip at the further side gradually rises, finally becomes perpendicular, and then is reversed by the complete overturn of the fold.



FIGS. 15, 16.—Diagrams illustrating the changes of dip and strike in the development of an overturned anticline.

In no case were continuous outcrops of that character found, but the plan used was to select some unusually hard layer or layers involved in the overturn, and to trace them partly by means of outcrops and partly by means of the scattered blocks on the surface, which resisting decay would indicate the presence of the hard layers beneath. Many of the overturns in the eastern part of the area were worked out in this way.

To resume, overturns may be suggested or located: (1) by the existence of anticlines to the east or west of a given locality; (2) by the prevalence over an unusually broad area of high dips in one direction; (3) by topographic relief; (4) by the exposure in parallel outcrops of deep-seated beds.

## VI. DETAILED STRUCTURE ON THE EASTERN SHEET.

The detailed structure will be described under the artificial divisions made by the two map sheets of the area. The two general divisions of the eastern sheet may be studied under:

1. The Caddo Valley.
2. The area of drift, the Chalybeate mountain being taken as the northern edge of the area of drift.

### *Eastern Portion of Caddo River Valley.*

The Caddo valley may be divided into an east and west portion, the dividing line being in range 22 W.

As will be explained more fully elsewhere, the topography of the portion of the eastern sheet north of the Chalybeate mountain, while broken up by divides and ridges into minor valleys, is a broad valley, differing in many ways from the country south of Chalybeate mountain.

*Blakeley Creek Anticline.*—The limits of this anticline were not definitely determined, but the ridge produced by it is between 100 and 150 feet high and five miles long, running from 4 S., 18 W., section 27, to 4 S., 19 W., section 26, along the south side of Blakeley creek. The ridge is of novaculite, but the novaculite bed is only poorly exposed. The ridge is serrated (as illustrated under Prairie Bayou anticline, Fig. 16), steep on the north side, the south side forming a water-shed to Prairie Bayou. It is highly probable that this anticline is continued further east, connecting with the one a mile and a half north of Social Hill.

*Minor Anticlines.*—Two minor anticlines were found in 4 S., 18 W., south half of section 29.

By minor anticlines is meant those in which the evidence of folding is meagre, or which could not be traced or other evidence of their existence found, or in which the thickness of the beds would indicate a small fold compared with the majority of folds. The evidence in most of these cases is only negative, but many of these so-called minor anticlines may prove to be quite as important as some which better exposures have disclosed more satisfactorily.

*The Prairie Bayou Anticline.*—Fig. 17 will give an idea of the structure of the Prairie Bayou anticline and of its accompanying topography, which may be taken as a type of the serrated ridges. The topography is a gentle slope draining from the top of the ridge next north leading to a long narrow valley, perfectly flat and covered by a deposit of novaculite gravel. This little valley is bounded on the south by a nearly perpendicular bluff 100 feet high, at whose base flows Prairie Bayou. From the top of the bluff the ground slopes gently south.

The anticline was first observed in the prairie from which Prairie Bayou takes its name in 4 S., 18 W., section 33. At that point it seems to be an overturn of the type C′D′, Fig. 14 (preceding chapter). From here it can be traced up the valley of Prairie Bayou, keeping close to the township line between 4 and 5 S., until in 4 S., 19 W., section 31, it becomes a simple anticline. The head of the east and west valley is at this point. It is crossed by the Arkadelphia-Hot Springs road in 4 S., 20 W., section 36, about an eighth of a mile north of the township line. The existence of several good springs on the axis along its western part should be noted. Westward from where it is crossed by the Hot Springs road the country is flat, and no indication of the axis is found until in 4 S., 20 W., section 31, where an anticline brings novaculite to the surface on the Big Hill creek. The ridge is 75 or 100 feet high and half a mile long; it is probably a continuation of the Prairie creek anticline.

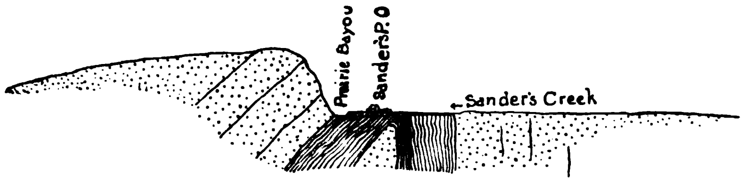


Fig. 17.—Section across Prairie Bayou anticline at Sanders Post-office.

*Valley Fork Overturn.*—In 5 S., 20 W., on the line between sections 3 and 4, De Roche creek cuts through a fifty-foot ridge a couple of hundred yards north of the crossing of the old Malvern-Murfreesboro road. The upper beds of the novaculite appear at the surface, but in a very small exposure. The structure appears to be an overturn. In 5 S., 20 W., section 6, on Big Hill creek, dips in the shale suggest that this overturn crosses the creek a little north of the half mile line. In 5 S., 21 W., section 4, on the Valley Fork of Point Cedar creek, half a mile north of Valley post-office, a seventy-five foot ridge is cut by the stream, exposing novaculite in thin ledges for a total thickness of 100 feet. The dip is perpendicular, indicating an overturn of the type G′H′, Fig. 14. The connection between this and the first exposure is doubtful, but having the same structure, and being in the same strike, it may be assumed that they are the same. West of the exposure on Valley Fork, the overturn can be traced into an anticline which is crossed by a branch of Point Cedar creek in 5 S., 21 W., section 7, northeast quarter. The strike from Valley Fork west is a little south of west. No trace of it was found further west, unless a small anticline on Cox's creek in 5 S., 22 W., section 9, southwest quarter be a continuation of it.

*Minor Anticlines.*—A small anticline is crossed by the Arkadelphia-Hot Springs road in 5 S., 20 W., in the south half of section 1; and another in 5 S., 20 W., north half of section 9, by De Roche creek.

*Bayou Delile Overturn.*—The Bayon Delile in its upper course runs east for some distance along the foot of a 75 or 100 foot ridge, finally turns south and cuts through the ridge in 5 S., 18 W., exposing an overturn in the gap with its overthrow to the south. This overturn shows again in perpendicular dips in 5 S., 19 W., section 15. It appears again to the south in 5 S., 20 W., just south of the northeast corner of section 16, on De Roche creek. It has not been found further west.

*Minor Anticlines.*—In 5 S., 20 W., section 16, close to the southwest corner, on a small branch of De Roche creek, is a small anticline, and again in 5 S., 21 W., section 13, is another or possibly a continuation of the first. In section 26, on the Caddo an anticline with a southwest strike shows very nicely. In 5 S., 22 W., southeast quarter of section 17 and southwest quarter of section 16, near the south section line, anticlines are exposed on Cox's creek. Also in the southeast quarter of section 15 a small anticline is exposed on a tributary of Cox's creek.

Through the centre of 5 S., 21 and 22 W., runs a belt about two and one-half miles broad in which the strata are nearly horizontal, the dip varying from 0° to 25° a little east of south.

*De Roche Creek Anticline.*—In 5 S., 20 W., the De Roche creek anticline is crossed by the Arkadelphia-Hot Springs road in the centre of the northeast quarter of section 36. Half a mile further west, where the axis is crossed by De Roche creek, Mr. Branner found it well exposed in the bank of the creek. The belt of north dips, a mile broad here, becomes narrow to the west until, as it enters 5 S., 21 W., it is less than a quarter of a mile broad, the axis being crossed by Big Hill creek half a mile from its mouth. It is crossed by the Caddo a mile west, in the northeast quarter of section 35, the strike being deflected a little south of west. It has not been identified further west.

The connection of the axis exposed on De Roche creek with that on Big Hill creek may be strongly questioned, even though the evidence obtained points that way. Theoretically it would be more satisfactory to connect it with the Big Hill creek anticline next described.

*Big Hill Creek Anticline.*—Just at the mouth of Big Hill creek in 5 S., 21 W., section 36, a ridge (140′) juts boldly out, the rock showing a dip of 88° S. As an anticline crosses the Caddo a mile west of this point in section 35, in the same strike, it is probable that the high ridge is in the axis of an overturn. This ridge is continued west of the mouth of Big Hill creek, forming a narrow divide between the Caddo and Big Hill creek which here runs east and parallel to the Caddo a quarter of a mile before running into it. The south side of this divide is for some distance composed almost entirely of a few bedding surfaces having a dip of 78° S., 2° W. For a mile or two north of where this anticline is crossed by the Caddo the structure is not clear, the dip varying rapidly; evidences of a fault are abundant, but the amount of throw could not be determined.

*Caddo River Anticline.*—The Caddo river anticline is thought to start in an anticline near the Ouachita river, a little south of the centre of 5 S., 18 W., which is crossed by the military road east of the centre of section 29.

In 5 S., 19 W., an overturn which has been assumed to be on the same anticlinal axis shows nicely on Waterhole branch, a tributary of De Roche creek, in the southern part of section 34. The overthrow is to the north, of the type G'H', Fig. 13, and an approximate correlation of strata is possible. In the northern part of township 6 S., ranges 19 to 22 W., is a long shale valley just north of the Chalybeate mountain, occupied to the east by De Roche creek, further west by the Caddo river, and still further west by Brushy creek. In various parts of this valley there is much indirect evidence of an anticline or overturn, but, aside from those mentioned above, at only two places was direct evidence obtained, and that was not very satisfactory. In 6 S., 20 W., section 10, near the northwest corner is a round mound 80–100 feet high giving a dip of 75° N., 7° E. on the north side and 60° S., 2° W., on the south side; and in 6 S., 21 W., northeast quarter of section 12, at the bend in the Caddo there is some appearance of overturning. Scattered perpendicular dips in shales on about the same line would suggest that an anticline or overturn passed through the two points mentioned.

### *Western Portion of the Caddo River Valley.*

In this division the structure is in several cases well displayed by anticlinal ridges which rise sharply from the broad valleys here predominating. The structures in these broad valleys is obscure, as might be expected, and in some portions the shale and interbedded sandstones have been twisted, faulted and jammed together until they defy all attempts to work out the original structure.

In 5 S., 22 W., Dr. J. P. Smith reports[1] four anticlines north of the Caddo river, the most southern of which is probably the same as the overturn giving the novaculite ridge north of Rock creek. It is probably this anticline which appears at the bend of the Caddo in 5 S., 23 W., section 17.

*Sugar Loaf Creek Anticline.*—In 5 S., 23 W., in section 1 or 2, near the section line, on Sugar Loaf creek is one of the few examples of an anticline where the axis is exposed, showing the beds closely bent on themselves. This exposure occurs at a road crossing where the creek makes a sharp turn to the east. It may be a continuation of one of the anticlines found by Dr. Smith.

*Caney Fork Anticline.*—In 5 S., 23 W., at the bend of the Caddo in section 11 is another case of an overturn showing well in the axis.[1] The axis is crossed by the Caddo again in section 16 near the mouth of Caney Fork. It forms a fifty-foot ridge running along the south side of the Caddo. In section 16 it is crossed by the river again just south of where it turns east, and again a quarter of a mile further west in section 17. In 5 S., 24 W., there is an overturn in the northern part of section 24 showing poorly on and near the Amity-Rock creek road. This may be a continuation of the preceding, and if it is, it is probable that this anticline may be considered as running up the Rock creek valley near the middle east and west section line of the township. It is the determining factor in the structure of the northern part of Pine mountain.

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[1] *Geol. Surv. of Ark.*, Rep. for 1890, Vol. iii, Mount Ida sheet.

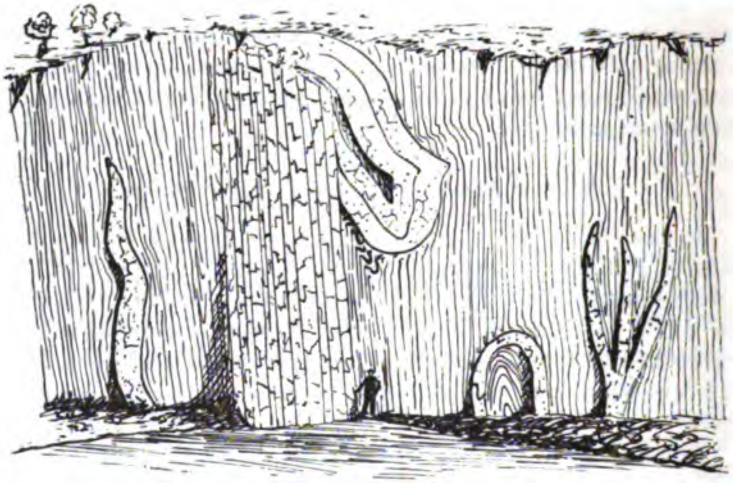

FIG. 18.—Contorted sandstone, shale, and novaculite exposed on the Caddo; 100 feet wide by 50 feet high.

In 5 S., 23 W., the northwest corner of section 21, on the Caddo, is one of the best exposures of the thin bedded novaculite and silicious shales and in the shales, on either side are good examples of contorted strata. Fig. 18 shows the wrinkling of these beds. There is also here a small but good example of a reversed fault having a throw of two and one-half feet.

*Sugar Loaf Mountain Anticline.*—In 5 S., 23 W., the northeast quarter of section 14 is a sugar-loaf-shaped knob of novaculite about 200 feet high making a conspicuous landmark, as the country for a few miles in every direction is comparatively level. This may be a continuation of the Haw Knob anticline, the evidence being insufficient to decide the question.

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[1] Photographs were obtained of many of the more interesting structural features of the region, but through an accident nearly three dozen of the best negatives were destroyed when it was too late to replace them.

*The Haw Knob Anticline.*—The Haw Knob anticline is first met with in a small ravine in 5 S., 23 W., about the centre of section 22. Half a mile southwest it is crossed by the Amity-Caddo Gap road, novaculite being exposed on either side of the road. Running southwest the novaculite produces a ridge which, though broken at two places, rises until at the western end, in the northeast quarter of section 29, where it is nearly three hundred feet high, it forks and ends abruptly. Farther west it appears to be continuous with an anticline on a branch of Antoine creek in section 30 northwest quarter and another anticline a mile further west in 5 S., 24 W., section 25, quarter of a mile north of the centre. The intermediate structure, however, is too broken to allow of direct connection being traced.

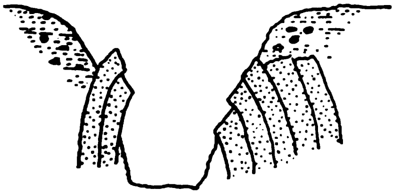

FIG. 19.—Section across a stream following an anticline.

This structure seems to show that Pine mountain, running east and west through the centre of 5 S., 24 W., is synclinal in its structure.

*Minor Anticlines.*—Between the Haw Knob and Amity anticlines the structure seems to be a syncline with the layers near the surface crumpled into a number of small folds. Along the Amity-Caddo Gap road in 5 S., 23 W., section 27 and 22, several anticlines are exposed. On the Caddo, in 5 S., 23 W., section 13, two overturns are exposed, one on the east bank close to where the Caddo crosses the south section line of section 13, and the other on the western side at the mouth of a small drain a little below where the Caddo crosses the west section line of section 13. The latter fold is a gaping anticline along which the stream flows. Fig. 19 shows a section across the fold. Exposures of igneous rocks are common in the region of these small anticlines.

*Amity Anticline.*—The Amity anticline is first noticed as a nose on the Caddo in 5 S., 23 W., near the centre of section 24. By means of a quartzite layer it was traced southwest into the novaculite ridge just north of Amity. It makes a low rise, exposing novaculite just east of the Amity-Hot Springs road in the southeast quarter of section 27; it forms the low ridge, seven hundred yards long, just north of Amity. This anticline can be traced by means of the large novaculite blocks strewn on the ground for a quarter of a mile west of the end of the ridge along the direction of the strike. Where it crosses a small drain in section 33 the horizontal outcrops of the rocks are sharply bent, without fracturing, through an arc of 110°. In the northeast quarter of section 31, an anticline in the same strike crosses a tributary of the north fork of Antoine creek. It has not been distinguished further west. Near the last mentioned exposure is a curious example of faulting of the rocks; it is illustrated in Fig. 20. This fold is of interest as being the most southern anticline to bring thick bedded novaculite to the surface. The structure is overturned where the novaculite is exposed.

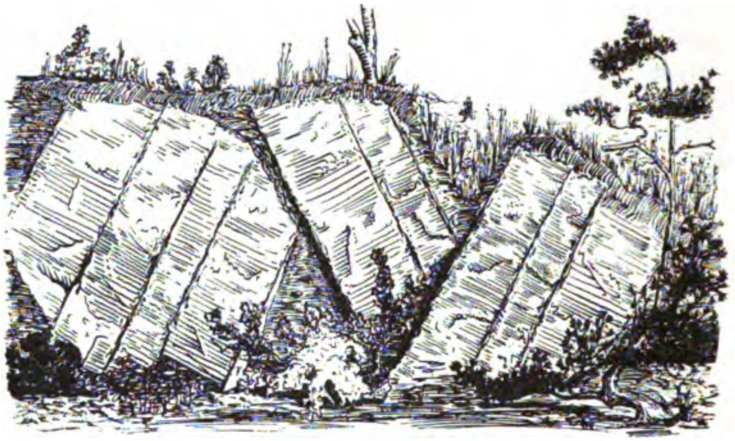

FIG. 20.—Faulted sandstones near Amity, Clark county (5 S., 23 W., section 30, S. E. quarter).

*Minor Anticline.*—In 5 S., 23 W., section 31, the southeast quarter, the dips indicate the existence of an anticline which is seen again in the same strike in 6 S., 24 W., section 2, where a small drain crosses the township line, near the north and south half-mile line of the section. This region between the Amity and Big Bear anticlines has been very badly crushed in 5 S., 23 W., sections 31 to 33. Fig. 21 is an example of crushing in shale exposed in a creek bottom in section 33, northwest quarter. In the southwest quarter of section 33, at the junction of two small creeks, is a fault with an offset in the outcrop of several yards, the sandstone layers being sharply jammed together and the shales tightly squeezed. Fifty yards from this point up the stream that enters from the west, the way the shales are crowded upon the end of a hard layer of sandstone suggests that the movement may have taken place since the stream eroded away the part of the hard layer which is gone (see Fig. 22).

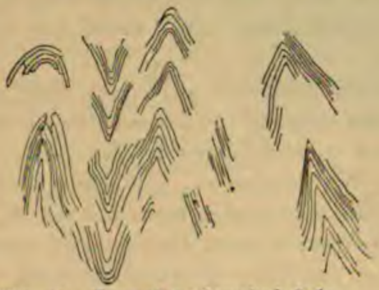

FIG. 21.—Examples of crushed shale in 5 S., 23 W., section 33.

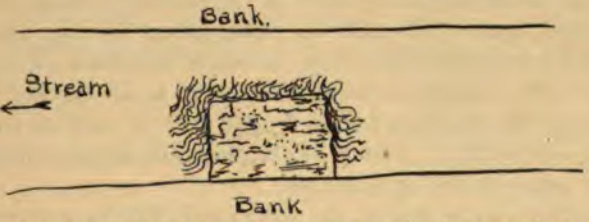

FIG. 22.—Shale in the bed of a stream showing secondary movement.

*An Overturn.*—In 5 S., 22 W., section 32, near the northwest corner are evidences (stronger in section 31, north of centre of section) of an overturn. The overturn follows up a little creek, the thin bed of novaculite and siliceous shale being exposed along the axis. In 5 S., 23 W., the axis strikes S., 20° W., across section 33 to 36, being readily traced by the fragments of novaculite over the surface. Passing into 6 S., 23 W., it follows the same course, the novaculite being exposed on both sides of the axis. In 6 S., 24 W., it crosses the north fork of Antoine creek just north of the crossing of the Alpine-Kirby road, where the anticline is no longer overturned.

*Big Bear Mountain Overturn.*—The Big Bear mountain overturn is almost in the strike of the last-mentioned one, but at the eastern end it seems to be deflected to the south. This anticline starts in 6 S., 24 W., section 11, southeast quarter, runs a little north of west for half a mile, then turns and runs S., 70° W., into 6 S., 25 W., on the western sheet, the southeast quarter of section 14 at the crossing of the Kirby-Murfreesboro road.

The Little Bear mountain, to be described later, is in this same strike, but its eastern end is deflected south, much as the eastern end of the Big Bear mountain is; otherwise the Bear mountains and the preceding anticline might be considered as a single anticline from the Caddo to the Little Missouri.

The Big Bear mountain anticline produces a high, sharp, irregular ridge. This ridge, which is about three hundred feet high, rises from a low, flat country and so makes a conspicuous landmark. It is the best example of an overturned anticlinal ridge in the region. The crest is sometimes as sharp as the roof of a house, the hard layer which makes this crest in many places forming the south flank of the mountain for a score or two of feet from the top with a dip of 67°. In several places where there is an exposed dip on the crest of ten or fifteen feet in length, springs start out from the very top of the ridge. In 6 S., 24 W., between sections 16 and 17, it is cut square in two by Gap creek.

While this may be due to the same causes that have allowed the main streams to run south across the strike of the beds, in this case the explanation seems to be that it is due to a backward cutting stream, an excellent example of which is a small stream on top of the ridge farther east. One of the little channels starting from a depression in the crest, as shown in Figs. 23 and 24, has cut its way along the top but on the side of the crest opposite to that down which it flows. This has continued until the channel extends for some distance along the top and has made a deep gap of the original depression from which it flowed. Given time enough, there will be formed at that point a gap cut clear to the bottom. The structure of this ridge can be seen at the gap, and at a few places along the top.

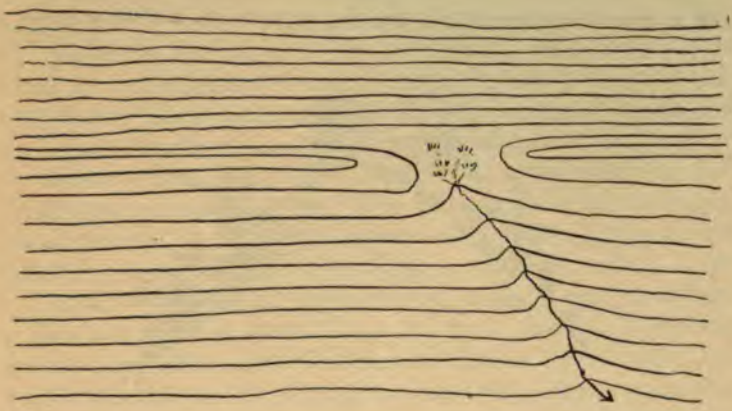

Fig 23 Early stage

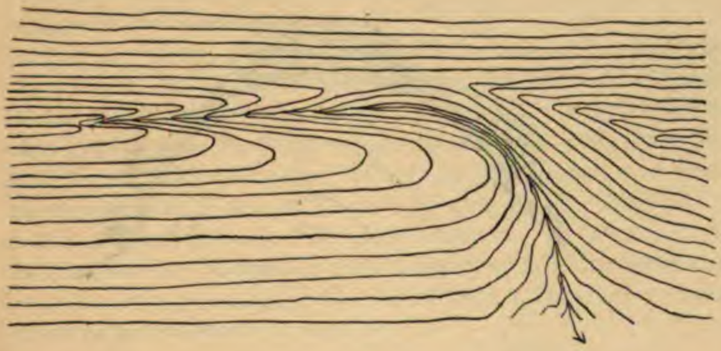

Fig 24 Later stage

FIGS. 22, 24.—Top of Bear Mountain, showing the development of a gap.

*Alpine Anticline.*—The Alpine anticline was first noted in 6 S., 22 W., Sec. 9, northeast quarter, in parallel outcrops of thin bedded novaculite and siliceous shale. It is crossed by the Alpine-Amity road half a mile northwest of Alpine. In 6 S., 23 W., it can be traced across sections 13, 14, 15 and 16, having a strike a little south of west. It appears to be crossed by the Amity-Murfreesboro road in section 19, southwest quarter. It has not been found to the west.

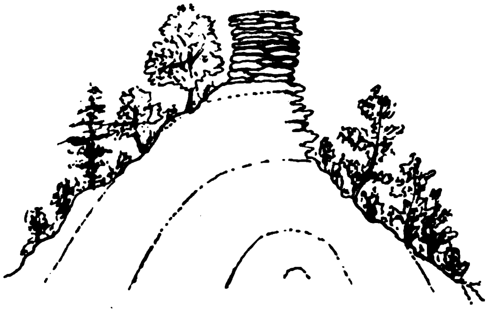

Fig. 25

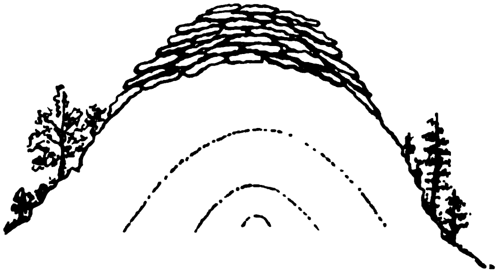

Fig. 26

FIGS. 25, 26.—Profiles of Antoine mountain, Pike county, Arkansas.

Minor anticlines occur in the same township southeast quarter of section 8 and north half of section 17. Their extent is unknown.

*Antoine Mountain Anticline.*—Questionable traces of the Antoine mountain anticline appear in 6 S., 23 W., near the centre of section 22. In section 19, it forms a ridge extending westward into 6 S., 24 W., through the south half of sections 23 and 24, and probably forms the ridge across the township along the south side of Woodall's creek. The main ridge is two hundred to three hundred feet high, and is chiefly interesting on account of the anticlinal wall on its summit. This (see Figs. 25 and 26) is a low irregular wall about a quarter of a mile long, from the side resembling an old, ruined fortress. It varies in height and thickness. On the north side it is in places 15 to 20 feet high; on the south side it is frequently 40 feet high, and in thickness it varies from a wall from 3 to 6 feet thick to a mound-shaped pile of stones. The layers are not continuous, but the break is not due to faulting. The wall is composed of a pile of lenticular rock masses suggesting that while being bent the layers give way in small blocks, and these, under great pressure or tension, have elongated and assumed the shape and position as shown, and have been left behind by erosion. The theoretical consideration of this is taken up in VIII. The rock at this point is a firm white standstone showing little or no signs of metamorphism.

*Minor anticlines.*—There are two anticlines in 6 S., 24 W. One first noted in section 24, southwest quarter, was traced a little south of west to the centre of section 27. It makes a one hundred foot ridge and probably continues in the same course westward. The other one forms the low ridge just north of Caney Fork post-office, running from the centre of section 26 through the south half of section 27, and probably continues westward. Judging from the fact that traces of manganese show at the top of the last-mentioned ridge, the heavy novaculites, or the horizon at which they occur, cannot be far below the surface.

### *The Region of the Overwash.*

As only four of the anticlines in the region of the overwash were definitely found at more than one locality, those four will be spoken of first.

*The Mill Creek Anticline.*—In 7 S., 21 W., northwest quarter of section 24, on Mill creek, an anticline is reported by Dr. O. P.

Hay[1] having a strike about 20° north of west. In this same strike Prof. T. C. Hopkins of this survey found an anticline on Bell's creek in 7 S., 21 W., section 18, northwest quarter, and also in 7 S., 22 W., section 11, southwest quarter, on Terre Noir creek, This anticline having a strike of N., 7° W., runs at a high angle to the general trend of the structure of this region.

*Straight Mountain Anticline.*—The relation of the Straight mountain anticline to the structure of the Chalybeate mountain to the east is not known; it is assumed as starting at Antoine creek in 6 S., 23 W., section 33, southeast quarter. It produces an anticlinal ridge, known as the Straight mountain, from two hundred to three hundred feet high, running a little south of west into 6 S., 24 W., section 36, and from this point is continued as the Wall mountain. It is broken at one point by Kirkland creek, which makes a gap in it.

*Wall Mountain Anticline.*—Wall mountain anticline is a continuation of the Straight mountain fold, and runs south of west to the Little Missouri river, which it reaches in 7 S., 25 W., southwest quarter of section 7. Starting from the Hot Springs road in 6 S., 24 W., section 36, for about a mile it forms an anticlinal ridge three hundred feet high; beyond this a little stream has cut its way into the anticline, and lowered it somewhat. This gives an excellent example of a breached anticline (Figs. 27 and 28).

In the sections given in Fig. 27, I shows the profile of the high unbroken ridge in the background toward the east; II, III and IV are successive profiles coming toward the foreground (westward), showing the cutting down of the centre of the ridge by the stream which originally cut in, and now drains by way of the gap shown in section IV; the full line gives a section on the west side of the gap. One of the interesting features of this ridge is shown in the illustration. This is a great wall, at one place about sixty feet high, crowning the summit of the north arm of the ridge for more than half a mile. It is composed of a layer of hard sandstone eight feet thick, rising perpendicularly. The manner in which it has withstood erosion is due partly to its hardiness and partly to its being so exactly vertical that detached masses simply rest in their places. The outcrop of the same layer of rock shows along the summit of the southern arm.

This weathering of the rocks in vertical walls is not uncommon

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[1] *Geol. Surv. of Ark.*, Rep. for 1888, Vol. ii, p. 271.

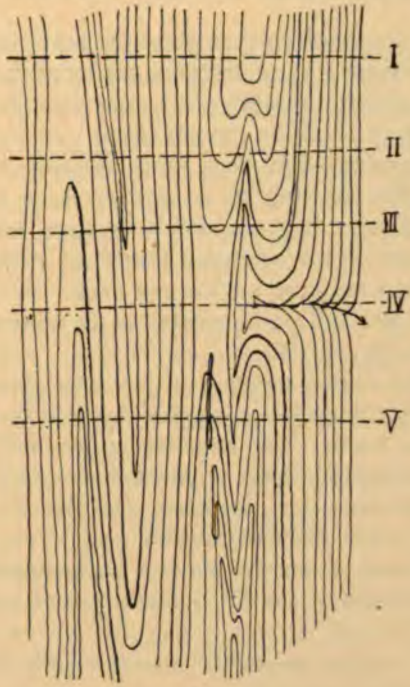

Fig. 27

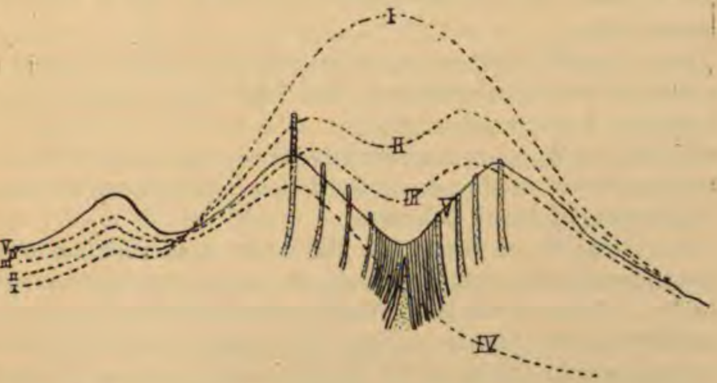

Fig. 28

FIGS. 27, 28.—Map and sections of Wall mountain.

on a small scale. In several places, where the heavy layers of sandstone are perpendicular at their outcrops, the topography is characterized by these irregular parallel walls, from two or three to ten feet high, running as far as the eye can reach.

*Suck Creek Overturn.*—The Suck creek overturn was only seen in 8 S., 23 W., first showing on a small creek in the southeast quarter of section 13. It is crossed by Antoine creek near the mouth of Suck creek in the southwest quarter of section 11, showing nicely in a small exposure on the east bank. It was traced up Suck creek about two miles; it appears to be an overturn all the way. Its strike is N., 65° W.

*Other Anticlines.*—The structure of the Chalybeate mountain was not solved, but the evidence suggests that it is an underthrown syncline, with the Caddo river anticline on one side, and on the south side an anticline of which no trace was found, unless there could be considered as such, perpendicular dips in 6 S., 22 W., section 13, near where the old Camden road leaves the Arkadelphia-Mount Ida road, or an exposure of shales apparently in the axis of an overturn in 6 S., 20 W., northern part of section 26, on the Caddo.

In 7 S., 21 W., section 10, an anticline is crossed by a tributary of Winfred creek in the northern part of the section, and another is crossed by Winfred creek in the southwest quarter. These have a strike of S., 65° W. In section 6 an anticline is crossed by Bell's creek in the southwest corner of the section with an east and west strike.

In 6 S., 22 W., section 36, an anticline was found at the end of a ridge; it probably continues to the Terre Noir, forming a ridge which runs a little south of west.

In 6 S., 23 W., there is an anticline or overturn just at the south township line in section 34 on the Antoine. It may be the cause of the valley of White Oak creek.

In 7 S., 23 W., it is probable that there is an anticline in the east and west valley running through the centre of sections 12, 11, 10, etc. Traces of manganese found near Story's store, section 10, southeast quarter, tend to confirm this supposition. In the centre of the township the strata for several square miles are so nearly perpendicular that a variation of a very few degrees gives the appearance of an anticline, so that it is impossible to tell which are anticlines and which are not. In section 22 is a large, flat area, and the evidence of an overturn here are somewhat stronger, chiefly the presence of shales with north and south dips. In the southern part of section 27, on the west bank of Antoine creek, a long bluff, seventy-five feet high, gives an excellent exposure of rock, and on either side of one point the layers bend toward each other in such a way as to suggest the axis of an overturn. Bluff mountain, a quarter of a mile farther south, also gives a fine exposure. An anticline probably crosses the big river-bottom in section 34, 7 S., 23 W.

In 7 S., 24 W., high dips and a ridge one hundred feet high, crossing Wolf creek near the centre of section 21, suggest the probability of an overturn with a strike S., 70° W. This is in the strike of an overturn on Prairie creek, to be described later.

## VII. Detailed Structure on the Western Sheet.

### *Township 4 South.*

*Rachel Mountain Axis.*—Rachel mountain is a novaculite ridge in the northern part of 4 S., 30 W., and has been described in the report on novaculite.[1] Its axis crosses the Brushy Fork of the Cossatot in 4 S., 30 W., section 5, southwest quarter. It ceases to be a novaculite ridge before reaching the Brushy Fork. In the same strike in 4 S., 32 W., section 1, half a mile south of Cove, an anticline is crossed by the line road, and traces of it are found in 4 S., 31 W.

*Buffalo Creek Anticlinal Axis.*—This axis is reported by Mr. Means[2] as crossing the Brushy Fork in 4 S., 30 W., section 7, the southwest quarter, near the mouth of Horn creek.

In 4 S., 31 W., it was noted again in section 12 and in section 10; the presence of igneous rock and the topography across that row of sections suggest its continuity in a due west direction.

In 4 S., 32 W., Mr. Means found the axis crossing the Old Line road near the middle of the section line between 11 and 12. A few uncertain dips indicate that it continues westward, and that it determines the Buffalo creek valley.

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[1] *Geol. Surv. of Ark.*, An. Rep. for 1890, Vol. iii, p. 262.

[2] Mr. J. H. Means, assistant geologist of this survey, worked up considerable of the area included in 4 and 5 S., 30 and 32 W. Most of the structure in 30 W. was gone over to get its connection and relation to the structure further east. That in 4 and 5 S., 31 and 32 W., is largely taken directly from Mr. Means' notes.

Mr. Means also reports an anticline or overturn on Brushy Fork in 4 S., 30 W., section 17, northwest quarter.

*Barn Creek Anticline.*—Raspberry mountain is a novaculite ridge crossing 4 S., 29 W., near the centre, and reaching the Cossatot in 4 S., 30 W., section 14, southeast quarter. Following this strike there is an anticline in sections 17 and 18, south part, which Brushy Fork crosses three times with an S-shaped curve, and in the southwest quarter of section 18 it is crossed by Rock creek.

Further west it is followed by Barn creek, and shows as an anticline near where the Old Line road crosses Barn creek in 4 S., 32 W., section 13.

To the west Mr. Means found this axis to be replaced by one a quarter of a mile further south. Barn creek swings south and follows the last axis quite closely across 4 S., 32 W.

*Pontiac Anticline.*—The end of a long novaculite ridge crosses the Cossatot in 4 S., 30 W., northwest quarter of section 22, just north of Pontiac post-office. It runs out as a ridge a mile to the west where it has a strike a little south of west. In this strike, in section 20, the northwest quarter, an anticline is crossed by Brushy Fork.

West of this point no anticline was found until 4 S., 32 W., section 19, where Mr. Means reports an anticline crossing Hickory creek near its junction with Buffalo creek.

*Anticlines on the Cossatot.*—In 4 S., 30 W., two small anticlines are crossed by the Brushy Fork in section 20, one near the north section line and the other a little more than a quarter of a mile further south.

About a quarter of a mile from the south side of section 20 (4 S., 30 W.), Brushy Fork and the Cossatot are separated by a high but narrow neck of land, ten to twenty yards wide. They diverge, however, and flow together a mile further down. On the Cossatot side of this neck is exposed the fault shown in Pl. VIII.

This same fault shows again in section 21 at the first bend in the Cossatot south of Pontiac post-office. It is really a double fault, as shown in the Cossatot section on Pl. I.

In the same township, section 30, near the half-mile line, the Cossatot crosses an overturned anticline. A quarter of a mile below, in the southwest quarter of section 29, the Cossatot crosses another anticline, and near the south section line of section 29, it crosses still another. This last anticline is in the same strike as one crossed by Baker creek near the south section line of section 25 of the same township. In section 31, southeast quarter, the Cossatot crosses an overturned anticline, as shown in Pl. II.

*Hickory Creek Anticline.*—In 4 S., 31 W., section 26, southeast quarter, an anticline is crossed by Flat creek. In this same strike Mr. Means reports an anticline crossed by the Old Line road in 4 S., 32 W., section 25, southwest quarter. Going westward it forms a low ridge which separates the two branches of Hickory creek. This fold was not seen west of sections 28 and 33. An anticline was found by Mr. Purdue in 4 S., 29 W., section 35.

A few other minor folds were noted.

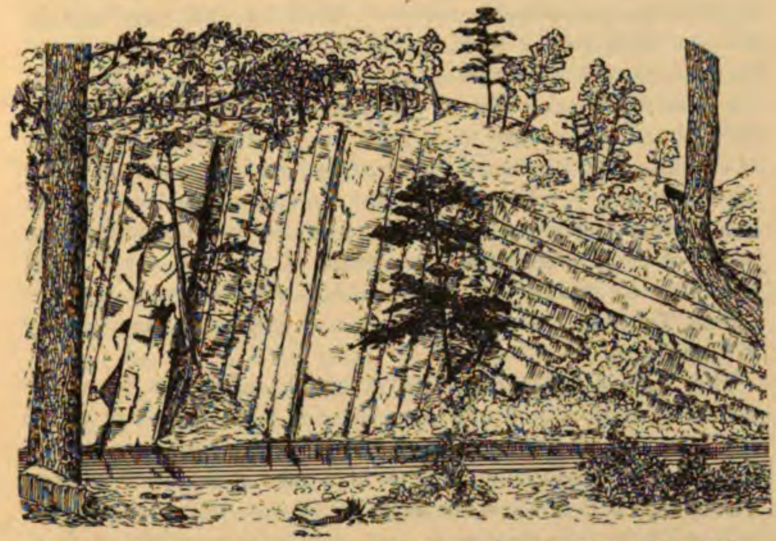

FIG. 29.—Fault on the Cossatot near the Mouth of Brushy Fork (4 S. 30 W., Sec. 20).

### *Structure in Township 5 South.*

*Novaculite Ridges.*—As the novaculite ridges have been described in detail in the report on novaculite[1] they will only be mentioned here. In 5 S., 25 and 26 W., the northern two tiers of sections are occupied by novaculite ridges; Brook's mountain, North mountain, Warm Spring mountain, Line mountain, and others. In 5 S.,

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[1] *Geol. Surv. of Ark.*, An. Rep. for 1890, Vol. iii, Chap. xiii.

27 W., the end of Line Mountain crosses sections 1 and 2, and Raven mountain, with a south of west strike, enters sections 4 and 5. Between sections 5 and 6 it is cut by the Little Missouri river, the anticlinal structure showing distinctly. West of the Little Missouri it strikes a little north of west, and under the name of Prairie mountain crosses the northeastern section of 5 S., 28 W., gradually entering 4 S., 28 W. It is crossed by the Saline at Moore's mill, in section 31, and it comes to an end a mile or two further west.

In 5 S., 31 W., a novaculite ridge, called the Cross mountain, rises in section 2 and runs out at the Line road in 5 S., 32 W., in the northern part of section 1.

In 5 S., 32 W., the southern part of section 1, are two short novaculite ridges in the same strike. The Line road passes between the two through what is known as "the gap." In the southeast corner of section 2 another ridge rises and runs west to the gap at the head of West creek, in the southwest quarter of section 3. West of this gap it rises to a height of 450 feet, and is known as Potato hill, then it runs a little south of west and passes out of the State at section 7. Between sections 11 and 14 the South mountain begins, strikes west for two miles, where it is cut by the head waters of Cross creek, then runs south of west and passes out of the State in section 18. These ridges continue west into the Indian Territory, but how far and how important they become is not known.

*Ball's Branch Anticline.*—Ball's Branch anticline is crossed by the Saline river in 5 S., 28 W., section 6, near the centre of the section.[1] In 5 S., 29 W., this same anticline passes through sections 1 and 2, crosses Harris Fork in section 2, northwest quarter. Though the anticline was not found to the west, ridges which occur in its strike suggest that it, at least, continues across the northern edge of 5 S., 29 W.

In 5 S., 30 W., the Cossatot crosses an overturn near the north section line of section 6.

*The Watkins' Mill Overturned Anticline.*—The Watkins' mill fold is a simple anticline where crossed by the Saline in 5 S., 28 W., section 5, on the south section line.

Where it is crossed by Harris Fork at Watkins' mill, in 5 S.,

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[1] Practically all the structure of ranges 28 and 29 W. was worked out by Prof. A. H. Purdue, Professor of Geology at the Arkansas Industrial University, formerly assistant on the Geological Survey.

29 W., in the southeast corner of section 3, a recent exposure made in the bank shows the strata making a complete overturn. Prof. Purdue reports this to be an unusually fine illustration of an overturn. The overthrow is to the south. Though this fold was not found further west, the monoclinal ridge just north of it was traced across the township, indicating that the anticline continues across the township with a strike a little north of west.

In 5 S., 30 W., there is probably an overturn in sections 6 or 7—an eastward continuation of the Cross mountain. Only north dips were found, however.

*Minor Anticlines.*—In 5 S., 28 W., section 8, northeast quarter, the West Saline crosses an anticline a little below Lance's mill, and in the centre of the southeast quarter of the same section there is another one. In 5 S., 29 W., there were found, corresponding to these two anticlines, two doubtful anticlines on Harris Fork; one a quarter of a mile south of Watkins' mill in section 10, and the other a quarter of a mile north of the southwest corner of section 11.

*Prior Ridge Anticline.*—In 5 S., 27 W., the structure and topography suggest an overturned anticline in the northwest corner of section 17. It is overthrown to the north. At the Little Missouri it is hidden in bottom land, but a short distance west of that stream it makes a ridge between White Oak creek and Clover creek, which gives evidence of anticlinal structure. This ridge was traced a little south of west to the Saline, where the structure is anticlinal. From the Saline to Harris Fork it could not be traced, but an anticline crossed by Harris Fork in 5 S., 29 W., northeast quarter of section 15, is in the same strike and may be the same axis. This last anticline may also be on the same axis as an anticline on Moore's creek, section 16, northwest quarter; the intermediate topography exhibits no clear structural relations.

An anticlinal ridge extends from Moore's creek to the Cossatot; the anticlinal structure is shown where it is cut by Moore's creek in 5 S., 29 W., northwest quarter of section 16. The ridge then runs a little north of west to 5 S., 30 W., southwest corner of section 12, showing the anticlinal structure north of Eldridge post-office in 5 S., 29 W., section 18, northern part.

In 5 S., 30 W., it is known as Prior's ridge, and it runs due west from section 12, the anticline showing where cut by Baker creek in the southwest corner of section 11, and as an overturn where cut by the Cossatot in section 7, southeast corner. From the Cossatot westward the shales which are exposed on the Cossatot have been eroded, producing in 5 S., 31 W., the Prior creek valley. This anticline, if produced into 5 S., 32 W., will join with the South mountain anticline.

*Minor Anticlines.*—In 5 S., 29 W., a small anticline is crossed by Harris Fork in section 15, the southeast quarter. In 5 S., 30 W., parallel outcrops of the thin novaculite seem to indicate an anticline or overturn in section 17, northeast quarter. In 5 S., 32 W., section 16, northwest quarter, two small anticlines are cut by Cross creek.[1]

*Baker Spring Ridge Anticline.*—In 5 S., 27 W., the Little Missouri river crosses an anticline in the northwest quarter of section 16. This anticline runs a little south of west, forming a two hundred foot ridge between Clover creek and James creek. In 5 S., 28 W., it is crossed by the Saline in the southeast corner of section 16; from this point it runs due west, being crossed by Harris Fork in 5 S., 29 W., section 15, in the southeast corner. On the south side of the anticline, between Harris Fork and Moore's creek, is a two hundred to two hundred and fifty foot ridge, highest at the Harris Fork end. It passes south of Baker Spring in 5 S., 20 W., section 14, southeast corner, and where cut by Baker creek, in section 15, southeast corner, there is one of the best exposures of an anticline in the whole area.

Going west the ridge made by this fold rises to a height of two hundred to two hundred and fifty feet. It is crossed by the Cossatot in the southeast quarter of section 17. In the centre of section 17 is the fine exposure known as the Falls of the Cossatot. The topographic effect of these heavy ledges is seen in the long high ridge between Prior creek and Cow creek, which runs across 5 S., 31 W. In the southeast quarter of section 14 and in the same strike to the east, shales are exposed structurally identical with the shales just under the heavy novaculite exposed in the Prairie mountain anticline on the Little Missouri river. Baker Sulphur Springs issue from this shale.

West of the Cossatot Mr. Means found this anticlinal axis in 5 S., 32 W., section 13, southeast quarter.

*Mill-site Branch Anticline.*—In 5 S., 27 and 28 W., the Mill-site branch anticline was not surely found, but the presence of thin-bedded novaculite shales, horizontal dips and the topography suggest its existence parallel to, and a little over a quarter of a mile south of, the last-described axis. In 5 S., 29 W., it forms the valley of Mill-site branch through sections 23 and 22. At the mouth of the creek a small fall in Harris creek offers some water power. North and south of the Mill-site branch valley are high ridges, the southernmost one being synclinal in structure. From Harris Fork to the Cossatot in 5 S., 30 W., section 21, northwest quarter, the continuity of the structure is clearly defined by the long ridge north of the Harris Fork valley and ridges between Baker creek and the Cossatot in 5 S., 30 W. Mr. Means crossed the anticline in the northwest quarter of section 20, but it was not found further west in 5 S., 31 and 32 W. To the east of the Little Missouri no anticlines were found in this strike, but the topography of the Pine mountain in 5 S., 26 W., in section 15, south of Lodi post-office, gives every evidence of being an anticline, probably an overturn.

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[1] All structures on Cross creek were worked out by Prof. A. H. Purdue.

The ridge, which, for the most of its length, is not conspicuous, here becomes one hundred and fifty feet high, and this anticline again may be in the same axis as the overturn south of Rock creek post-office.

*Blocker Branch Anticline.*—Corresponding in strike with the overturn in the south part of Pine mountain in 5 S., 24 W., as carried out by the topography, is an overturn on the Little Missouri river in 5 S., 27 W., sections 21–23. This overturn is visible at a number of places along the river, the bending showing nicely at the foot of the road just north of Mr. Logan's, north of the centre of section 22. This fold is remarkable for the low dip on the south side.

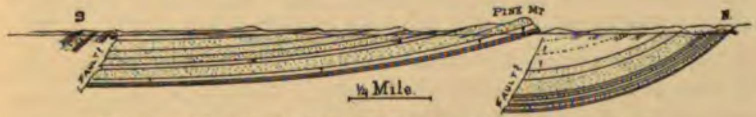

FIG. 30.—North-south section along the Little Missouri river.

The exposure as given in Fig. 30 is two miles long. Pine mountain, shown in this section, is an abrupt ridge on the northern edge of sections 26 and 27 over two hundred feet high, though it maintains this height for only a mile or two to the west. There is probably a fault just north of this ridge, as seen in the section in Fig. 30.

West of the Little Missouri the course of the anticline is shown by the low ridge north of Blocker branch. But it could not be traced to the Saline river, and, as the structure there is quite different, it will be considered as confined to 5 S., 27 W. Attention is called to the northeast direction of the streams in sections 28–30.

*Sulphur Spring Branch Anticline.*—The structure in 5 S., 29 W., is not clear, but the topography and the shales go to show that the Blocker branch axis is followed by the Sulphur Spring branch anticline in sections 22–24, and from Harris fork to Baker creek the shale it exposes is a factor in the breadth of the valley of Harris creek.

In 5 S., 30 W., from Baker creek west, this fold forms a two hundred and fifty foot ridge, the structure showing at several places where cut by ravines. In this ridge the shales appear well up in the ridge, while blocks of novaculite lying on the highest point of the ridge indicate the presence of the layer of thin novaculite.

Reverting to the question of the age of this thin bed of novaculite, and referring to section 2, Pl. ii, it is readily seen that if the novaculite occurring thus on top of this ridge be Lower Silurian, as the main body of novaculite is supposed to be, we should have at this point a belt from one to two miles broad in which almost nothing but Silurian rocks are exposed.

To the west of the Cossatot no anticline was noted in this strike, but it is probable that it influences the topography of Cow creek valley in 5 S., 31 W.

*Harris Creek Anticline.*—The Harris creek anticline is crossed by the Saline in 5 S., 28 W., at the north section line of section 28. Thence it passes nearly due west, helping to form the high ridge south of Sulphur spring branch, in 5 S., 29 W. It then becomes part of the Harris creek valley, and is followed by that creek most of the distance. It is crossed by the Cossatot in 5 S., 30 W., at the north section line of section 26. The structure of the fold is well shown where cut by the Cossatot. From this point it trends due west, forming a high ridge for over two miles on the south side of the Cossatot, which, for that distance, flows through a deep narrow gorge between this ridge and one just north of it made by the Sulphur spring branch anticline. The river flows in the trough of the syncline between these two anticlines, in places being walled in by parallel, almost perpendicular layers of sandstone, which give it the appearance of a canal. There is an anticline on this same axis in 5 S., 31 W., section 26, northern part.

*Minor Anticlines.*—In 5 S., 28 W., an anticline is crossed by the

Saline river in section 28, northwest quarter, a quarter of a mile south of the Harris Fork axis. At the same distance south of the Harris Fork axis, where it is crossed by the Cossatot in 5 S., 30 W., is an anticline corresponding to the one exposed on the Saline.

In 5 S., 32 W., a small anticline is exposed on the Rolling fork in section 25, a little south of the centre of the section, and a quarter of a mile further south another one is crossed by the same stream. In the strike of these two anticlines, two anticlines are crossed by Cross creek in section 29, southwest quarter. They may therefore be considered as on the same axis.

*Umpire Anticlinal Axis.*—In 5 S., 28 W., the Umpire anticline forms a ridge in the northern part of sections 34 and 33, and is crossed by the Saline in the northwest of the northwest of section 33. Further west in section 31 it is crossed by a small stream in the southwest of the northeast, near an old mill. In 5 S., 29 W., it is indicated by the dip in section 35.

In 5 S., 30 W., it is crossed by the Cossatot in the centre of the northwest quarter of section 36. In 5 S., 32 W., section 32, southwest of northwest, an anticline is crossed by Cross creek. Though in the same strike this can hardly be assumed to be a continuation of the anticline further east.

*Possum Creek Anticline.*—In 5 S., 29 W., an anticline runs close to the south township line. In 5 S., 30 W., sections 35 and 36, the Cossatot crosses the same anticline near the south township line. The topography, which east of the Cossatot is a valley, to the west becomes a prominent ridge. It runs west along the township line south of Possum creek and is found to be an anticline where crossed by the Rolling Fork just south of the township line, in 6 S., 32 W., section 2, at the ford of the Eagletown road. Igneous rock is exposed in the axis at the last named place. There is an anticline crossed by Possum creek in 5 S., 31 W., section 35, northwest of southeast, but the topography shows that it cannot be on this axis.

*Other Anticlines.*—In the Carboniferous portion of 5 S., 25 and 26 W., the structure is but little exposed. The streams seldom have deep channels and the dips found are universally south, except for a quarter of a mile along Bear creek in 5 S., 25 W., section 34, northwest of northwest. This last mentioned dip discloses the only anticline definitely known in the township, though in some places the bending of the rock suggests overturns. Slickensides abound all over the region, but there is an unusually fine example of them in 5 S., 26 W., section 24, southeast quarter, where the edges of the heavy layers having a dip of 25° are polished horizontally. Such cases are common and are evidence of faulting, even though no other testimony be obtained. In this case Self creek has followed the fault and has been carried three-quarters of a mile eastward.

In the same section, a little south of the centre, the rocks and topography suggest an overturn with a strike of about S., 73° W. In 5 S., 26 W., section 28, southwest quarter, on Rock creek in the same strike, the rocks are sharply curved, and further west in section 31, southwest of northwest, an anticlinal axis shows well on the east branch of the Little Missouri. The structure at this last exposure is shown on the left of Fig. 30, the fault being introduced to account for the sudden change of dip.

In 5 S., 27 W., section 25, southwest of southeast, on the Little Missouri river, a heavy mass of sandstone, showing no bedding and of unknown extent, appears to have been forced up or down through a thick exposure of thin-bedded shaly sandstone. The great quantity of slickensides in every direction in it seems to preclude the idea of its being an unconformity.

### *The Structure in Township 6 South.*

*Little Possum Creek Anticline.*—In 6 S., 28 W., the Little Possum creek axis is crossed by the Saline river in section 8, northwest of the northwest. It is exposed next in 6 S., 30 W., forming a ridge south of White Oak creek and showing well its structure at the end of the ridge in the northwest of the northwest of section 10, and also in section 9, northwest quarter. In 6 S., 31 W., this axis is followed by Little Possum creek. In 6 S., 32 W., it is crossed by the Rolling Fork in section 12, northwest quarter.

*Galena Synclinal Axis.*—Just south of the last described anticlinal axis and parallel to it are two other anticlines. The northern one is crossed by the Saline river in 6 S., 28 W., section 8, southwest of northwest, the other one is crossed by the same stream half a mile further south. In 6 S., 29 W., only the southern one was found, following the south section line of sections 10, 11 and 12. Galena post-office is on the syncline between these two anticlines. The two folds form a single flat-topped ridge which slopes off to the south very gradually. In 6 S., 30 W., the northern one is crossed by the Cossatot in section 9, southwest quarter, and the southern anticline in section 17, northwest quarter. Further west their presence is indicated only by finding outcroppings of igneous rock in 6 S., 32 W., section 9, southeast of southeast, in the strike of the northern anticline and in the strike of the southern one in section 14, northwest quarter, on Rolling Fork and on the bluffs above.

*Brushy Branch Anticline*—The Brushy branch anticline is the northernmost of the three anticlines that are crossed by the Little Missouri river in 6 S., 27 W., section 12. It is in the northeast of the northwest quarter, nicely exposed in shales, and is overthrown to the north. Just north of it in section 1, where the river runs southwest, a syncline shows on the east bank. It was noted in section 9, northeast of southeast, south of Brushy branch, with a strike a little south of west. Following the topography across 6 S., 28 W., an anticline is crossed by the Saline in 6 S., 29 W., section 24. From here the axis is supposed to run south of west across 6 S., 29 W. Then turning west it crosses 6 S., 30 W., connecting with the anticline crossed by the Cossatot, in section 30, the southwest quarter of the northeast quarter. In section 29 this anticline forms a high ridge north of Sweeney's creek. Due west of this another anticline is crossed by the Rolling Fork in 6 S., 32 W., sections 25 and 27, and again in section 30, northeast of the northwest, an outcrop of igneous rock indicates its presence.

*The White Oak Creek Anticline.*—The White Oak creek anticline is the second of those crossed by the Little Missouri in 6 S., 29 W., section 12. The south side of the anticline appears, as a small monoclinal ridge, the single layer which forms the body of the ridge being bent sharply at the top. It then forms the ridge which runs south of west, south of White Oak creek and the Brushy fork of the Saline. This ridge, while not sharply defined, is quite a high one, forming a watershed between Brushy Fork and the drainage to the south and southeast. In 6 S., 29 W., it is crossed by the Saline in the southeast quarter of section 26, and again in the northeast quarter of section 33, the structure here appearing to be an overturn overthrown to the south. It then turns due west, forming a broad flat-topped ridge across the southern part of 6 S., 30 W., south of Hunter's creek, being crossed by the Cossatot in section 31, northeast quarter, the anticline still being overthrown to the south. The high ridge between Sweeney's creek and Hunter's creek is a good example of a synclinal ridge. From the Cossatot the axis strikes a little south of west, the overturn flattens down and is crossed by the Rolling Fork in 6 S., 32 W., the southwest of the southwest of section 34.

*The New Hope Anticline.*—The third axis is crossed by the Little Missouri in 6 S., 27 W., in the southwest quarter of section 12. It appears to form the ridge upon which the western half of the Star-of-the-West and New Hope road is built. The lack of marked topography prevented its being followed further west.

*The Self Creek Overturn.*—In 6 S., 26 W., section 11, northeast quarter, is a good example of an overturn of the type shown by E′F′ in Fig. 14. This is probably a continuation of an anticline crossed by Bear creek at the north township line of 6 S., 25 W., section 4. The strike would carry it south of west to a probable overturn in the top of Pine mountain south of Star-of-the-West, 6 S., 27 W., section 13. But the topography does not sustain that view. The steep north side of the Pine mountain in 6 S., 26 W., has a strike a little north of west. No outcrops were found in this part of the ridge and all those found in adjacent territory have a strike a little south of west, so that the ridge, though so marked, may not conform to the structure in 6 S., 26 W. West of Star-of-the-West the Pine mountain is deflected until it strikes about southwest, the strike of the outcrops being the same. It ends abruptly at Fallen creek.

*The Gentry Overturn.*—South of Gentry post-office is a ridge two miles long, starting in a high knob at the southwest corner of section 7, 6 S., 25 W., and maintaining a height of one hundred and fifty feet in a south of west direction to the Little Missouri river. This ridge gives the appearance of being an anticline overthrown to the north.

*Bear Creek Anticlines.*—An anticline is crossed by the Kirby-Murfreesboro road in 6 S., 25 W., in the southwest corner of section 11. In the northeast corner of section 19, on a small tributary of Bear creek, the dip suggests the presence of an overturn overthrown to the north; this may be a continuation of the Little Bear mountain overturn. In 6 S., 26 W., the Little Missouri crosses an anticline or overturn in section 24, the northwest quarter.

*The Little Bear Mountain Overturn.*—The Little Bear mountain overturn is in 6 S., 25 W. It begins in section 22, eastern part, at the Kirby-Murfreesboro road. Rising abruptly to a height of about three hundred feet it runs at first northwest, then gradually swings around until it runs a little south of west and ends abruptly in the northwest corner of section 21. On the top of this ridge the rocks, though not rising into a wall, present very much the same peculiar structure as on the top of Antoine mountain. The sandstone on top of this ridge, when not examined closely, bears a striking resemblance to novaculite in color, fracture and general appearance. The structure is an overturn overthrown to the north.

*Chimney Rock Anticline.*—In 6 S., 26 W., section 36, southwest of northeast, a mass of rock juts out from the east bank of the Little Missouri, forming a perpendicular cliff one hundred and forty feet high and tapering from a broad base to a narrow top. It is known throughout the region as the "Chimney Rock." The dips along the river for a mile or two are within a few degrees of perpendicular, and so give no clue to the structure, but the most probable explanation is that the "Chimney Rock" is in the axis of a closely pressed anticline. Several anticlines may be crossed by the river in sections 25, 26 and 36 without their presence being recognized. One case on the west bank in section 26, southeast of northeast, where a mass of rocks having the same appearance as the "Chimney Rock," but on a smaller scale, is thought to be an anticline. The topography to the west strengthens this view.

The Chimney rock anticline, or some anticline very close to it, probably explains the structure of Jenkins' spring ridge, a high ridge running a little south of west across the southern row of sections of this township, and is also responsible for the high ridge to the east of the river. Evidences of an anticline appear in 6 S., 25 W., centre of section 27, on the Kirby-Murfreeeboro road.

### *Structure in Townships 7 and 8 South.*

*Silver Hill Anticlinal Axis.*—In 7 S., 30 W., section 6, southwest quarter, the Cossatot crosses two anticlines, one at Antimony Bluff, and one about three hundred feet further north. In 7 S., 31 W., the topography indicates that one or both of them passes nearly due west, forming the high, flat-topped ridge upon which Silver hill is situated. In 7 S., 32 W., an overturn with a north dip is crossed by Robinson's Fork in section 8, northeast of the northeast. The topography between the two prongs of the Rolling Fork for several miles from their junction is extremely broken, but it shows the strike of the rocks.

*Minor Anticlines.*—In 7 S., 30 W., section 6, northwest quarter, a single exposure indicating an anticline was found on the Cassatot. In 7 S., 31 W., the Cossatot crosses two anticlines in section 12, one in the northeast of the northeast, and another in the northeast of the southeast. In 7 S., 32 W., the Rolling Fork crosses an anticline in the southwest quarter of section 15, near the mouth of Davis branch. It also appears to cross an overturn with north dips in section 16 east of the centre.

*Cave Creek Anticlinal Axis.*—In 7 S., 29 W., section 9, near the mouth of Cave creek, the Saline river crosses the Cave creek anticline. Going west it forms an unusually straight valley running a little south of west, down which Cave creek flows. This valley is continuous from the Saline to the Cossatot, but near the Cossatot it is deflected to the south, the axis appearing to be in a sharp ridge in 7 S., 30 W., the northwest quarter of section 20. This ridge ends abruptly in the northeast of section 20. In 7 S., 31 W., it forms the valley of a tributary of Stowe's creek, running through sections 22 and 23. It is here indicated only by the parallel outcrops of thin novaculite and siliceous shale. Through sections 19, 20 and 21 the axis is followed by Bellah creek, forming a broad valley to the Rolling Fork in 7 S., 32 W., section 27. The shales form bottoms on the Rolling Fork.

On the Saline river in 7 S., 29 W., section 16, its structure is that of a simple anticline. To the west, its structure could not be determined, but on Rolling Fork in 7 S., 32 W., low south dips of 10° to 15° point to a monoclinal structure. Fig. 31 shows the composite section exposed along the Rolling Fork.

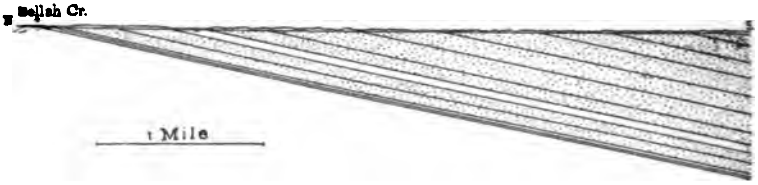

FIG. 31.—Section on Rolling Fork of Little river from Bellah creek southward.

*The Blue Ridge Anticline*—The topography strongly suggest that the Blue Ridge anticline is a continuation of the "Chimney Rock" axis which runs west through the Jenkins' spring ridge. Jenkins' spring ridge runs a little south of west to Fallen creek, and is cut by two creeks. At Fallen creek it is questionably anticlinal.

Then it runs due west to the New Hope-Centre Point road, where it turns a little north of west to the Muddy Fork. Here the structure is anticlinal. From Muddy Fork to Rock creek it has a south of west direction, and forms a high ridge in 7 S., 28 W.; in the southeast of the southwest of section 2 it forms a high knob. The anticlinal structure shows where the ridge is cut by Holly creek in section 9, northeast quarter, and by Rock creek in section 18, northwest quarter. From Rock creek west the high ridge continues, forming a prominent bluff where it meets the Saline in 7 S., 29 W., section 16.

*The Arsenic Cave Anticline.*—The Arsenic cave anticline was first noted by Mr. Purdue on Muddy Fork in 7 S., 28 W., section 12, northwest quarter. In section 9 it shows where cut by Holly creek in the southwest quarter of the southeast quarter. From

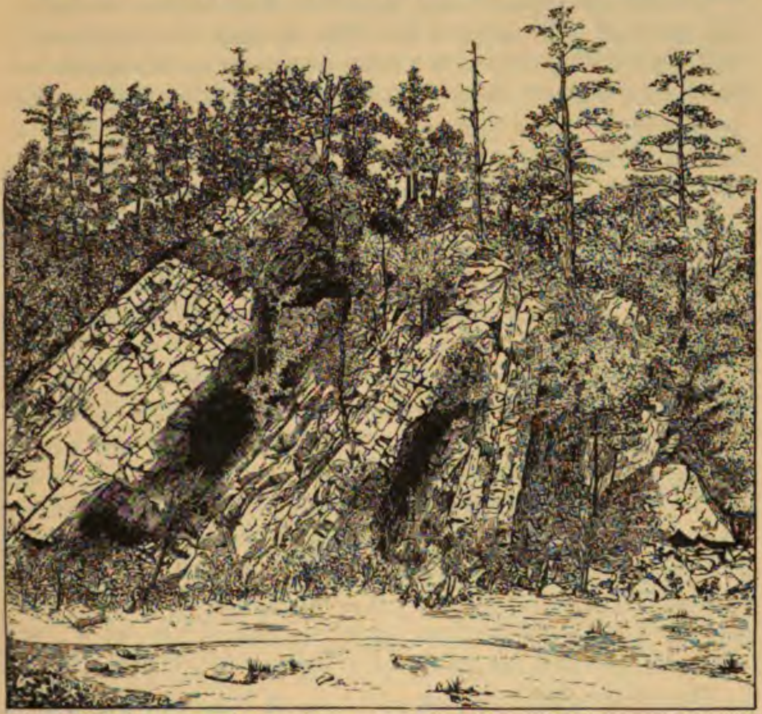

FIG. 32.—An overturned anticline at Arsenic cave on West Saline river (7 S., 29 W., section 21).

Holly creek to the Saline river it forms a high pointed ridge from two hundred to three hundred feet in height, the anticlinal structure showing in several places. At the Saline it is overturned, and where the axis crosses the river in 7 S., 29 W., section 21, northeast of southwest, there is a small cave known as Arsenic cave. Though the overturning does not show quite as plainly at the cave as in several places, this was the only point at which a photograph was obtained of the fold. Fig. 32 is a drawing from a photograph. This axis could not be followed west of the Saline, but it may have some connection with an anticline crossed by the Cossatot in 7 S., 30 W., section 33, in the northwest of the southwest quarter.

Another axis appears to run parallel to the Arsenic cave anticline but one-half mile south of it. This southern axis was found at three places. In 7 S., 20 W., it is crossed by the Muddy Fork in section 12, where it turns to the northeast, and by Holly creek in section 16, northeast quarter. No trace of it could be found on the Saline river. In 7 S., 30 W., it is crossed by the Cossatot in section 33 at the township line.

*Other Anticlines.*—In townships 7 and 8 S., 25 to 27 W., the structure is much obscured by the over-lying water-worn material and Cretaceous. An anticline is reported by Dr. Branner and Dr. Hay[1] as cut by Holly creek in 7 S., 28 W., section 28, northwest quarter.

Several minor anticlines show in the banks of the Cassatot in 8 S., 30 W., section 4, as shown in the Cassatot section, Pl. ii.

*Red Bluff Anticline.*—In 7 S., 25 W., a high ridge with a south of west strike makes what is known as Red Bluff where cut by the Little Missouri river in section 6, southwest quarter. The structure appears to be an overturned anticline with south dips. Following this strike in 7 S., 26 W., the dips give an anticline in section 8.

The Wall mountain anticline is shown by the topography to be continued across the northern row of sections of 7 S., 25 W., and south of Cow creek, but its extent to the west is unknown.

*The Muddy Fork Overturn.*—In 7 S., 25 W., section 10, northeast quarter, Prairie creek crosses what appears to be an overturned anticline with south dip. The topography strengthens this view. A high ridge which starts abruptly in section 12 crosses Prairie creek at this point and runs a little south of west to the Little

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[1] *Geol. Surv. of Ark.*, An. Rep. for 1888, Vol. ii, p. 286.

Missouri. At places the top of the ridge is strewn with great monoliths due to the outcropping of a heavy layer of sandstone. In 7 S., 26 W., occur parallel lines of similar monoliths sometimes combining to form a low wall. These were found in the south half of section 16, and north half of section 21, and suggest a similarity of structure or continuity with the overturn exposed on Prairie creek.

In 7 S., 25 W., the Muddy Fork crosses an overturned anticline in section 20, northeast quarter just west of Muddy Fork post-office. The strike places this upon the same axis as the Muddy Fork fold.

*Prairie Creek Anticline.*—In 7 S., 25 W., Prairie creek crosses an overturn in section 28, northeast quarter. This is one of the few cases where an overturn can be traced as it folds over, then under. This anticline is exposed also in section 30 on the Little Missouri river.

*Minor Anticlines.*—In 8 S., 25 W., some evidence was found of an anticline crossed by Prairie creek in section 5 near the north section line, and by the Little Missouri in section 6, northern part.

In 7 S., 25 W., section 20, west of the centre, Mr. Hopkins describes the nose of a ridge which, at this point, is very suggestive of an overturn with dips to the south.

In 7 S., 26 W., section 30, a mile north of Nathan, the perpendicular dips indicate the presence of an anticline, and Dr. Hay[1] reports finding an anticline west of this on the Muddy Fork, near the Nathan-Muddy Fork road.

## VIII. THEORETICAL DEDUCTIONS.

In this chapter we shall discuss briefly some of the problems presented by the structure described in the preceding chapters.

*Original Extent of Folded Strata.*—A folded layer of rocks does not cover as much space as the same layer spread out, nor would it be a difficult problem to ascertain the difference, if the folds were completely exposed. When, however, it is remembered that we have only an imperfect section along practically a single line (not even a plane), and in addition to this many of the folds are overturned, or so closely squeezed that their upward or downward extension may be a few hundred feet or several thousand feet, and also that no correlation is obtainable in most cases, it is readily seen that the problem is a difficult one.

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[1] *Geol. Surv. of Ark.*, An. Rep. for 1888, Vol. ii, p. 284.

The following method was adopted for obtaining an estimate of the original extent of the folded strata upon the supposition that the folds are not broken, but remain complete until eroded.

North and south sections on the scale of one mile to the inch were made, as for example, down the Cossatot; the structure and dips accurately placed on it, and the folds theoretically completed, and then measured with a scale. The folds were made as short as could be done consistently, and the result may therefore be regarded as conservative. Still this method makes no pretense to accuracy, and the limit of error is certainly not more than twenty-five per cent.

The two best examples gave the following results: The Cossatot section, which is now twenty-four miles long, is estimated to have had an original length of thirty-five miles. The Antoine section, at present twenty miles long, is estimated to have had an original length of thirty-five miles.

If it be assumed that the movement took place from the south, the strata restored to their original horizontal position would spread over the territory now included in all of Clark, Pike, Howard and Sevier counties and the northern part of Nevada, Hempstead and Little River counties.

Had such a method been adopted as that used by Prof. Claypole in determining the original extent of a section across Cumberland county, Pa., there is little doubt that instead of thirty-five miles, we should have had between fifty and one hundred miles, as the sections on Antoine creek and Little Missouri river, with their many overturns, present much the same character of structure.[1]

Without going into a full discussion of the subject, we are led to conclude, that while there has been an apparent shortening of north-south cross-sections from their original position of not less than five or ten miles, and possibly much more, did we know the actual facts of the case, it is probable that such shortening has really been very small, and that the strata occupy nearly the same ground as that in which they were laid down.

*Direction of Movement.*—In determining the direction of movement three factors have been used: the dip of the axial plane of an anticline, or in the case of an overturn, the direction of overthrow; the direction of dip of faults parallel to the strike; the general character of folding considered over the whole of the disturbed region.

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[1] Claypole, *American Naturalist*, Vol. xix, No. 3, March, 1885.

Thus, in the case of overturns, if they are overthrown to the north, the dips being south on both sides of the axis, it is asserted that movement came from the south. In this region, however, we find overturns overthrown both to the north and south.

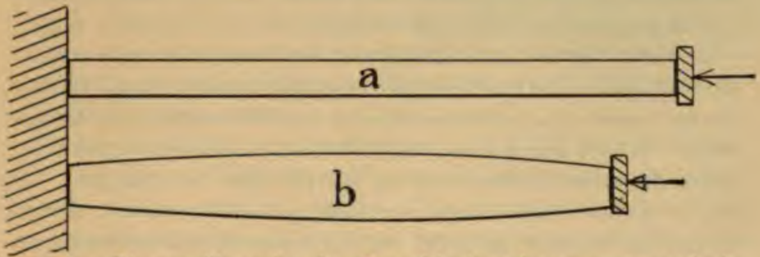
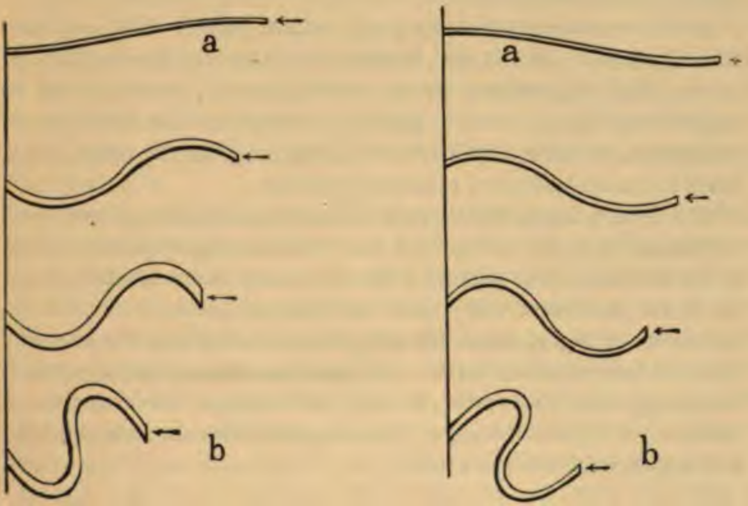


FIG. 33.—Diagram illustrating the effect of horizontal pressure upon a horizontal homogeneous bed.



FIGS. 34, 35.—Diagrams showing the effect of original dip upon ultimate structure.

An examination of the subject seems to show that the real determining factor in the direction of overthrow is the initial dip of the strata. Thus a perfectly homogeneous horizontal layer as in Fig. 33*a* subjected to horizontal pressure, evenly applied, will not tend to bend, but to be compressed, as in Fig. 33*b*. If, however, as in Figs. 34*a* and 35*a*, it have a slight initial dip, the horizontal force will, at the point or points of bending, be resolved into two components, one tending to compress and the other to bend. Bending may then take place, but all that is desirable to note here is that, if the bending is carried to overturning, the direction of overthrow is not determined by the direction of movement, but by the direction of dip, as suggested in Figs. 34*b* and 35*b*.[1]

It is true that as a rule this dip will be toward the open sea, and the testimony of other elements show that, in many cases at least, the movement or apparent movement has been from the shore seaward. In such a case the overthrow will be away from the shore, and so there would be a tendency for the rule to hold good that the overthrow is away from the direction of movement. But we are led by the facts observed in this area where there exist overthrows both to the north and south to believe that such reasoning from the direction of overthrow is reasoning in a circle and not to be accepted as trustworthy.

Another element is the direction of dip of faults. This, too, contains the same objection, for, as shown by Daubree,[2] faulting parallel to the strike is governed by the folding, and if, as we are led to suspect, the folding is not entirely governed by the direction of movement, we must consider the faulting as under the same limitations and therefore not a trustworthy factor.

If a section across the Appalachians from southeast to northwest be examined, it will be noticed that the folding, which is intense at the southeast end, gradually becomes more and more gentle until at the northwest end the strata become horizontal.[3] An examination of Fig. 1, shows the same thing; in this case the intensity dies out from south to north. In such cases the evidence seems to be strong, that movement, if any, comes from the direction of greatest or closest folding. This suggests that the movement in our region was from the south.

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[1] Dr. E. A. Smith has suggested the same explanation for overthrust and underthrust (*Am. Jour. Sci.*, April, 1893, p. 306), but as Mr. Ashley's paper was written before the publication of that paper his explanation is allowed to stand. —J. C. Branner.

[2] Daubrée, *Géologie Expérimentale*, Paris, 1879, p. 344.

[3] H. D. Rogers, *First Geological Survey of Pennsylvania*, *1857*.

*Bearing of Certain Features of the Region upon Theories of Mountain Making.*—Reference was made in the description of Antoine mountain (p. 273) to the peculiar appearance of the layers where closely bent in the axis of the anticline. They have the appearance of having broken into blocks, and of these blocks having adjusted themselves to their neighbors. The rocks on top of Little Bear mountain present much the same appearance. In neither case do the rocks show noticeable metamorphism, though they are slightly closer grained than most of the layers.

Probably bearing on the same subject are the many cases noted where solid layers are sharply bent into acute angles without showing any sign of fracturing.

It has generally been assumed where such close folding without fracturing occurred that it was due to the confinement put upon it by the enormous vertical pressure of superincumbent beds. It being thought that, though the layer were under shearing stress far beyond its ultimate strength, the great vertical pressure would be sufficient to close every incipient fracture.

Some interesting experiments have been performed by Mr. Bailey Willis of the United States Geological Survey[1] in studying the effect of a horizontal pressure on soft layers under a weight of half a ton of shot. Some of these conditions were produced, and a study made of their action by graphical statics. Very similar results were obtained, but they led to certain questions presenting themselves.

If we assume such a series of layers under a gradually increasing horizontal pressure, the time will come when the bending component of that pressure at some point of initial dip will be sufficient to overcome the various resistances and forces opposing it, and the layer will begin to bend. If, when the layer has bent slightly, we make another examination of the components, forces and resistances involved, we shall find that the slight bending has given the bending component of the original horizontal pressure an advantage, and it has increased at the expense of the compressing component. On the other hand the resistances and forces opposing it remain about the same, hence its movement would be accelerated, and soon the bending would go forward with a rush until finally the horizontal pressure is transmitted across the fold instead of along it. If the force not used up by the first fold were great enough other similar folds might be made.

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[1] Bailey Willis, *Transactions American Institute of Mining Engineers*, June, 1892, xxi, 551–566; Thirteenth An. Rep. *U. S. Geol. Surv.*

Figs. 33 to 35 outline the action, only the main or combined forces or resistances being given in the figures. The conditions assumed are similar to those of Mr. Willis' (L) model (not given in the paper referred to). In this case the forces are only considered in reference to the main heavy layer, the others being assumed to be soft shales with little power of transmitting pressure. The question then arises, How can bending take place unless the bending component be as great as assumed at the moment when bending begins? A study of the rocks of Antoine mountain and elsewhere has led to this suggestion. May it not be accomplished by a much smaller force by introducing the factors of great length of time in connection with viscosity of solids?

It is now generally held that mountain making is a process of thousands of years, the movement being, as a rule, so slow as to be imperceptible, and yet we still cling to the idea that the forces and resistances involved are such as would be involved in rapid laboratory experiments. Thus a bar of stone is placed in the machine for testing the bending strength, and the result obtained is used in the study of mountain making.

Experiments have shown that solids under pressure below their ultimate strength but above their elastic limit will flow in the same way as will a plastic substance like putty. They have also shown that the elastic limit becomes lower when more time is allowed the pressure in which to act; and examples have been found of marble slabs, which have lain many years, bending[1] under their own weight without fractures, though when first placed in position they would not have bent under several times that weight, and would probably have broken before bending perceptibly. In Mr. Willis' experiments it may be that the plasticity of the materials made up for the shortness of time in which movement took place.

We are led to the conclusion that the folding may be due in part to flow of the cold solid rock under a comparatively small pressure continued over a great length of time.

[1] Winslow, *Am. Jour. of Sci.*, iii, Vol. xliii, p. 133. Ashley, *Proc. Cal. Acad. of Sci.*, *1893*, p. 319. See also Gibbs, *Am. Nat.*, Vol. iv, Jan., 1871, No. 11, Salem, Mass., p. 695.

## IX. Post-Carboniferous History.

### *Period from Carboniferous to Cretaceous.*

If in the sections of Pl. II the strata be restored above the surface, it will be seen that a great amount of erosion has taken place. The fact that the eroded upturned edges of the Carboniferous rocks have the Cretaceous rocks resting unconformably upon them is sufficient evidence that this erosion took place between Carboniferous and Cretaceous times.

What was the extent and character of this erosion? Mention has already been made of the peculiar character of the topography along the southern border of the area. Thus, if we start from the level Cretaceous country and travel north over the Paleozoic, selecting a road which avoids the immediate neighborhood of the larger streams, as for example, the county roads to Amity from Arkadelphia, from Hollywood, from Clear creek, from Murfreesboro, the Old Drove road north from Nathan, the old Stewart road from Atwood toward Galena and others, we cannot help noting as we leave the Cretaceous border and proceed northward that the almost level character of the country continues without break, except where small streams have made small valleys. The elevation increases from two or three to eight or ten miles when east and west valleys abruptly end the level surface. The lateral extent of this flat country is governed by the encroachments of the nearest streams on either side. In some cases where the tributaries of the south-flowing streams run east and west the level topography reaches out from the main divides and forms flat, minor east and west divides, which extend almost or quite to the south-flowing streams and form bluffs on those streams from 200 to 300 feet high. In short, the whole topography suggests an original surface nearly level, but rising gradually to the north and west over all the southern portion of the region. Into this streams have later cut their channels, in some cases to a depth of 200 to 300 feet, and in many cases have eroded the surface to such an extent that all vestiges of its original character are lost. The present northern boundary of this flat country is exceedingly irregular, but in a general way is indicated by the northward extent of the Post-Tertiary drift upon the roads mentioned above, as shown on the maps. How far north the Cretaceous extended is not known. A quarter of a mile west of Star-of-the-West a single piece of Trinity limestone was found, and it is said that formerly such limestone was plentiful at that locality. In 7 S., 32 W., or 33 W., near the north township line limestone full of fossils is reported as occurring plentifully on a ridge west of Cross creek. This could not be verified. These suggest the possibility of the Cretaceous deposits having been originally laid down all over this region. This view is strengthened by the character of the Cretaceous deposits, limestones, chalks, etc., implying at least fairly deep waters over the region.

### *Cretaceous and Tertiary Periods.*

During the Cretaceous and Tertiary periods the southern part of Arkansas was the theatre of several gentle oscillations of level which find record in the varying deposits bordering on the south.

For the details of this history the reader is referred to the Survey's reports on the Mesozoic and Tertiary.[1]

We must, however, note the land epochs, as it was probably during one or all of these land epochs that the present drainage systems of our region were inaugurated and fixed. Two have been noted during the Cretaceous and another follows the Tertiary subsidence.

Frequent references have been made to the way the main drainage streams cut across the structure, being influenced by the strike of the folds only to a minor degree. In the novaculite area this feature of the larger streams is still more marked, the Little Missouri and Cossatot being good examples. In some cases these streams cut across high ridges, when, by a short east or west offset, they could have run around them.

Remembering that the Cretaceous strata were originally much thicker than they now are, if we replace these deposits, which have a gentle south dip, they would doubtless extend well northward toward or to the Ouachita mountains. Supposing now the movement of elevation takes place. These new strata would gradually become a land surface. Streams would start from the point of highest elevation and run seaward. If a map of western Arkansas and eastern Indian Territory be examined, it will be found that there is such a centre from which drainage flows in all directions. This centre is in the neighborhood of the Rich mountains, at the western end of the Arkansas base line. To the north runs the Poteau river, to the northeast the Fourche la Feve, to the east the Ouachita, to the southeast the Caddo and Little Missouri, to the south the West Saline, Cossatot and Rolling Fork, to the southwest the Mountain Fork of the Little river, and to the west the Black Fork of the Kimishi river.

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[1] *Geol. Surv. of Ark.*, Rep. for 1888, Vol. ii, p. 182; Rep. for 1892, Vol. ii.

We may then assume that that region was the centre of elevation for the land period that gave rise to the present drainage.

We can readily imagine a condition of things, such as at present exists in the Cretaceous region, having previously existed over the whole area. The creeks and rivers following the general slope of the Cretaceous strata, entirely unaffected by the buried Paleozoic sandstones. Then as they sink their channels until the Paleozoic strata are reached, they find it easier to continue sinking their beds than to force their banks and make new channels conformable with the softer rocks.

If next, we suppose that, due to shore conditions, the thickness of the beds diminished to the north, we can understand how erosion would first expose the Paleozoic strata at the north and the line of contact would gradually move southward until it reached its present position.

As erosion began to cut deeply into the Paleozoic strata, the minor streams yielded to the influence of structure and became in time structural streams, and the larger streams, though maintaining their first courses in a general way, became conformable to the structure in minor details of their courses.

In which of the land epochs the present drainage originated and became fixed we do not know. It must be remembered that these land periods each produced a nonconformity in the Cretaceous and Tertiary rocks, so that it is not impossible that all the effects of erosion during one land epoch may have been erased in the next subsidence, new beds being laid down and the next land epoch beginning a new system of drainage. However this may have been, the evidence seems to show, that, at the end of the land period following the Tertiary, the topography of most of our area was much as it is to-day, therefore it will be discussed at this point.

*Drainage of the Area.*—The direction of the main streams would be represented diagrammatically by drawing radiants from the centre of drainage at the western end of the Arkansas base line.

To the northeast of the Caddo are four smaller creeks, Blakely creek, Prairie creek, Bayou Delile, DeRoche creek. Between the Caddo and the Little Missouri are Terre Noir creek and Antoine creek. The still smaller creeks are shown on the maps. As a rule, the tributaries run at right angles to the main streams. Thus, the Caddo runs nearly east, its tributaries nearly all run south, and this same relation can be traced with but few exceptions to the Cossatot, which runs south, but has east and west tributaries.

Going from east to west the general elevation increases more rapidly on the north edge of the maps than on the southern; consequently the difference of elevation between points on the north and south edges of the maps is greater in the western part than in the eastern.

The effect of this is quite marked, both upon the character of the streams and upon the topography; this is still further intensified by the direction of the streams in the eastern part, giving them the advantage of the longest side of the slope. Thus the Caddo and other streams in that region may be characterized as a succession of long, deep pools connected by short rapids having only a few inches, fall. Further west the Cossatot and Rolling Fork are, for much of their courses, shallow, rapid streams with but few stretches of quiet water.

Comparatively speaking all the streams are rapid. The more western streams probably averages between fifteen and twenty-five feet fall to the mile; the Caddo has a fall of seven or eight feet to the mile.

In the same way the topography changes from east to west. In the east it consists of broad valleys with many bottoms along the streams. In the west the valleys are narrow, deep and steep-sided. In the Cretaceous area the smaller streams are mostly surface streams not having cut channels of any great depth. This, to a large extent, is also true of the smaller streams of the Caddo valley, though, where their courses compel them to cut across ridges, they become more rapid and have abrupt banks. In the western part, where the tributaries as a rule follow structural lines, they sink their beds rapidly in the shaly strata, producing deep, narrow ravines, and where these are quite numerous, the topography becomes exceedingly broken.

### *The Overwash Gravels.*

Spread over both the Cretaceous and Carboniferous areas is an overwash of gravels, sands and occasionally a little yellow clay. These deposits are of great thickness along the northern edges of the Cretaceous rocks, while, as a rule, they are but thin on the Carboniferous beds. These gravels and cobbles are well-rounded or flattened fragments of novaculite of almost every color, from black to white, yellow being most common, followed by gray, red, brown and a mottling of these. Sandstone boulders are also mingled with the novaculite pebbles. These water-worn boulders vary from the size of one's fist down, but occasionally they are as large as one's head. Sometimes a hillside is covered with the novaculite boulders bleached so white that they resemble snow.

Sometimes the gravels are cemented together by iron, forming a conglomerate. Sometimes beds of considerable thickness are thus cemented, as, for example, near Wolf Creek P. O., on Wolf creek, Pike county.

The character of the overwash gravels is well illustrated in a fresh cut near the depot at Arkadelphia on the side of the road running north to the business part of the town.

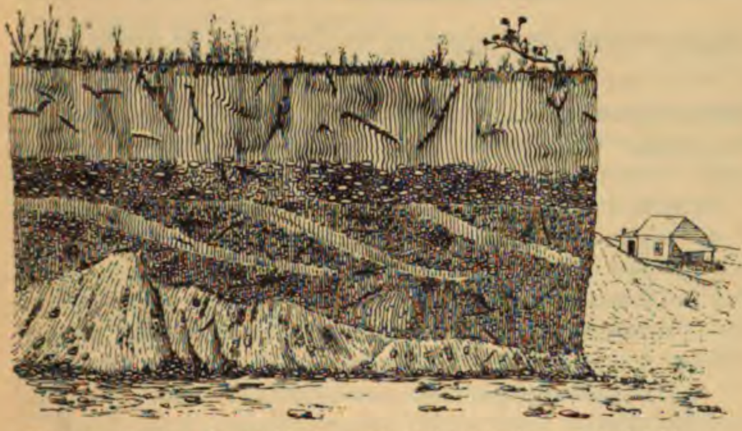

FIG. 36.—Section of gravel bed near the railway station at Arkadelphia.

| | FEET. |
|---|---|
| (*a*) A layer of sandy clay, red, mottled with gray, at the bottom all gray, at the top all red........ | 3½ |
| (*b*) A layer of yellowish red gravel from very fine to the size of a hen's egg or larger............. | 1½ |

| | FEET. |
|---|---|
| (*c*, *d*) A bed of fine gravel (*c*) into which there run thin layers (*d*) of sandy clay without gravel, the fine gravel being the size of a pigeon's egg and smaller | 4 |
| (*e*) Talus to level of road | 2–4 |

As the cut was but a few days old when noticed, it seems highly probable that the red color at the top of (*a*) is due to the oxidation of the iron, the color where freshly exposed being gray; the gradation from the pure gray at the bottom to the deep red at the top exhibits very nicely the process of oxidation.

The relation of the bed of firm sand to the other beds of that period is shown on Antoine creek in 8 S., 23 W. In section 14 it forms a ten-foot bluff for a thousand feet, overlying two or three feet of gravel.

At the Antoine crossing of the military road to Fort Towsen and above, section 24, it appears again, Fig. 37 being a cross section at that point. We have:

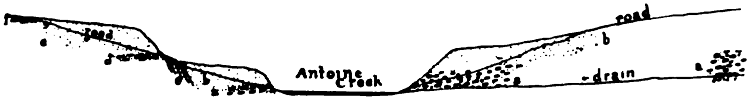

FIG. 37.—Section at the crossing of the Fort Towson road and Antoine creek (8 S., 23 W., section 24).

| | FEET. |
|---|---|
| (*a*) Bed of gravel dipping east or southeast and lying on a soft, friable sandstone dipping 45° south | 8 |
| (*b*) Bed of firm sand with same dip | 8 |
| (*c*) Outcrop on east bank of soft yellow or brown sandstone dipping 70° south, 25° west | 3–5 |
| (*d*) Thin bed of novaculite gravel | 2 |
| (*e*) Bed of very firm sand | 8–10 |
| (*f*) Gravel | ? |

The age of the sand in this case depends somewhat on the age of the uppermost gravel, which is evidently the younger. But the gravel on top may be a very recent deposit made by the creek.

The beds of gravel attain no great thickness in the Paleozoic region. In the northern part they usually consist of scattered boulders, all the finer material having been removed. At the northern edge of the area, over which it still exists in an undisturbed condition, it is comparatively thin. But going southward it gradually increases until, at Centre Point, there is an exposure of seventy-five feet of it in a bluff. Mr. Hill estimates that a mile south of Centre Point it has a thickness of two hundred feet.[1]

The undisturbed gravel deposits occupy an irregular area on the west side of the Ouachita river for a mile or two from the river, and from a mile south of Social Hill to Rockport. They occupy all of 6 S., 19 W., except the northwest corner. Passing westward the northern escarpment follows the Chalybeate mountain in an irregular line through 20 west, swinging south in ranges 21 and 22 west, it crosses range 23 west about in the centre of 7 south. It reaches this far north in each range to the west until the West Saline has been crossed, west of which gravel was only noted in spots.

North of this line gravel was found in nearly every township east of the West Saline river, occupying areas from five or six square miles down to a few acres.

Generally these consist of scattered boulders of water-worn novaculite; some show a little fine material as though they represented fragments of undisturbed deposits.

All the beds of the creeks which rise among the novaculite ridges contain more or less water-worn novaculite gravel, but in those in the northeast part of the region this gravel sometimes constitutes the valley bottom, the creek cutting down through it, and in places exposing a thickness as high as six feet. Prairie Bayou, Big Hill and Valley Fork of Point Cedar creek are examples of this kind. In the centre of a large curve in the Caddo in 5 S., 23 W., section 22, northwest quarter, the deposit of gravel reaches a depth of thirty feet. It is not probable that these are original undisturbed deposits, but remains of a subsequent deposit, made when erosion carried the gravel from the higher ground and filled the valleys faster than the streams could carry it off.

In 5 S., 28 W., section 24, Mr. Purdue found two elliptical knobs or mounds one hundred feet or more long and fifty feet high, which, to all appearances, seemed to be made up entirely of novaculite water-worn gravel. One of them is known as Round mountain.

*Distribution in Other Regions.*—Without asserting an exact correlation, it may be said that there occur deposits of approximately the same age and of the same character in Alabama, Mississippi, Texas and Indian Territory.[1]

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[1] *Geol. Surv. of Ark.*, Ann. Rep. for 1888, Vol. ii, p. 40.

*Age of the Gravel.*—No fossils have been found in these gravels, so that the only determination of their age possible is by their stratigraphic position. They lie unconformably on the Paleozoic and Cretaceous. Similar gravels overlie the Tertiary, and are therefore of more recent origin, and on that account the age of the gravels is given as Post-Tertiary.[2]

## X. ECONOMIC GEOLOGY.

### *Minerals and Stones.*

*Minerals.*—Many have been led by the disturbed condition of the layers all over this area to think that mineral of some kind must exist here in quantity. Much prospecting has been done and many thousands of dollars expended in sinking shafts and prospect holes, but all without results, except in a small belt in the northern part of Sevier county. For convenience it may be well to consider first this belt which is known as the antimony district.

### *The Antimony District.*

The ores found in this district have been discussed in the Survey's report on Gold and Silver, to which the reader is referred.[3] As Prof. Comstock misinterpreted the structure in this district, it may be well to state that more fully.

*Extent of the Antimony District.*—As defined by localities in which ore has has been found, the antimony district lies entirely in township 7 S., ranges 29–32 W. inclusive; in 7 S., 29 W., however, the Busby mine is the only place where ore was found. Thus it may be said to be about twenty-four miles long by four miles wide, and has a very slight south of west trend, occupying the northern part of the eastern townships and the central part of the western.

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[1] Tuomey, *Second Biennial Report on Geology of Alabama, 1858*, p. 144. Hilgard, *Report on the Geology and Agriculture of the State of Mississippi*, 1860, pp. 3–46. Hilgard, *Amer. Jour. of Sci.*, May, 1866. *Geol. Surv. of Ark.*, Rep. for 1888, Vol. ii, pp. 43–47.

[2] Mr. Ashley's paper was written before the publication of the report on the Tertiary of Arkansas by Professor Harris. The latter author has, in my opinion, solved the problem of the age of these gravels. He regards them as shore deposits "laid down under similar conditions, though by no means in the same geological epoch," and he thinks that their "rearrangement presumably took place before the close of the epoch represented by the underlying stratified beds." See *An. Rep. Geol. Surv. Ark.* for 1892, Vol. ii, 7–9. *The Tertiary Geology of Southern Arkansas.* By Gilbert D. Harris.—*J. C. Branner.*

[3] *Geol. Surv. of Ark.*, Rep. for 1888, Vol. i, p. 136, *et seq.* See also Wait, *Trans. of Am. Inst. of Mining Eng.*, Vol. viii, 1879–1880, pp. 42–52.

Prospectors report finding traces of stibnite north of this region, but as in no case has it seemed to warrant the expenditure of time or money in exploitation, the district may be considered as fully comprehended in the limits given.

*Structure of the District.*—The structure in this district is obscure, the topography is broken, and outcrops of bedded rock are scarce. Such structure as was obtained was derived partly from exposures in shafts and prospect holes. As shown in the Cossatot section of Pl. ii, there appear to be about half a dozen anticlines in the district, though only half that number could be found on the Rolling Fork and on the West Saline. As shown in the section, the anticlines are closely folded, giving many high dips. No evidence of faults, which play such an important part in Prof. Comstock's interpretation of the structure, was found, but this must be considered as having only a negative bearing, as faults doubtless do exist all through this region. The Silver Hill anticline or anticlines have a strike of less than 5° S. of W. The Cave creek anticlinal axis has a strike of from 5°–10° S. of W.

The rocks in the districts are the same as all over the region—shales, shaly sandstones and sandstones. The thin bedded novaculite occurs in such a way as to suggest that, if the strata under it are Silurian, then the Silurian is extensively exposed in this belt, if indeed it be not the predominating formation.

*Character and Occurrence of Ore Deposits.*—The ore deposits of this district are in the form of bedded veins. While they usually follow the bedding in strike and dip, they frequently run at small angles to the dip, and it is claimed that in a very few cases small deposits are found crossing the bedding, but none were seen. They occur mostly in shale, but though a contrary claim was made, they were also found in sandstones at several places. The veinstone is quartz and varies from a thin layer, in which the quartz simply forms a matrix for fragments of the country rock, to veins four feet thick and very pure. The ore occurs as lenticular masses in the quartz from two inches to twenty-two inches thick, and occasionally of considerable extent, as one mass is said to have yielded over seventy-five tons of clean stibnite. This quartz veinstone is frequently exposed at the surface as a low wall, and in one case in 7 S., 32 W., sections 8 and 9, this is easily traceable for nearly a mile. The veins are of such a character that there is always much uncertainty about the occurrence of paying ore. A shaft at the Valley mines has been sunk 230 feet and still shows good ore, while others have run out in a short distance below the surface.

Along the Rolling Fork exploration revealed twelve ore-bearing veins within two miles. In the region just south of Antimony City it is claimed that five leads or veins have been found.

Similar quartz veins are common north of this tract in townships 5 and 6 S., but no ore has been reported from them.

*Ores.*—The main ore and the only ore as yet found in paying quantities is stibnite. Silver and lead are found in small quantities. In still smaller quantities or occurring only as traces were found sphalerite, cervantite, jamesonite, pyrite, chalcopyrite, arsenopyrite, tetrahedrite, and a few others.

*Ores Outside of the Antimony District.*—There are a few places north of the antimony district where the general appearance of quartz veins suggests a similarity of conditions to those found in the antimony district. But, with these exceptions, the remainder of this Paleozoic area does not give evidence of containing ore of any kind in any quantity; in fact, in view of the careful prospecting that has been done and the negative results obtained, strengthened by a study of the geology of the region and the character of the rocks, the evidence seems to be against the existence of pay ore in the region.

*Silver.*—During the silver excitement a few years ago all the northern edge of this territory in the eastern part was thought to be included in the silver district, and a large portion of it was taken up in claims. Much prospecting was done and many shafts were sunk, but no one reports finding any silver, or getting an analysis that gave more than a trace of it.

Very recently a prospect hole has been started just north of Caney Fork P. O., based upon the finding of two or three small pieces of silver at that point. One of the pieces seemed to be almost pure silver, about the weight of a dollar. It had evidently been run out and worn smooth; it was certainly not as it came from the earth, though still in the condition in which it was found. The finding of Indian "tools and hammers" in the same locality might explain the presence of the silver. For the tools are undoubtedly Indian implements, such as are found all over the region, and instead of suggesting an old mine, suggest a camping place. The silver belonged to the Indians and was brought from nobody knows where.

Traditions of rich silver mines are plentiful, but they always go so far back and contain so many improbable factors that they may be dismissed as of no value except to entertain the traveler.

*Lead.*—Lead is often reported as having been found in the region. The localities given, though not definitely known, were all in the Caddo valley. It is possible that a little lead may occasionally be found, though the geology makes it appear improbable that it should ever be found in any quantity.

*Manganese.*—The northern portion of the region borders on the manganese district of southwestern Arkansas, and in a few instances traces of manganese were found on anticlines well in the centre of the region.

The ore, in quanties sufficient to color the joints in the sandstone, is quite common. Occasionally it occurs in small masses as a conglomerate or mixed with iron. The original bed, or more properly plane of occurrence, is a bed at the top of the novaculite series. It partakes of the same folding as the novaculite, and will be found, not as a level bed, but as an outcropping edge of the layer parallel to the neighboring novaculite layer, and, except as modified by the topography, usually running along the side hill of a novaculite anticline.

The ore occurs in pockets difficult to mine and generally in very small quantities. Those interested in the manganese of this part of the State should consult the Survey's report on manganese.[1]

*Iron.*—Iron as a commercial ore does not exist in this territory. A few loose pieces of impure bog iron ore occur especially around the chalybeate springs, where the sandstone is highly impregnated with iron. With these exceptions iron exists here only as the coloring and cementing material of the red and brown sandstones and conglomerates. Iron is sometimes found in the same bed as the manganese, but as such deposits are properly north of the area in every case, the reader is referred to the Survey's report on iron.[2]

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[1] *Geol. Surv. of Ark.*, An. Rep. for 1890, Vol. i.

[2] *Geol. Surv. of Ark.*, An. Rep. for 1892, Vol. i.

*Salt, Soda.*—Though indefinite reports of salt having been found in the region were frequently heard, all those that could be traced out proved to have come from wells or springs in the Cretaceous border on the south.

Soda is said to exist as an efflorescence in a cave on the Little Missouri in the northern part of 7 S., 25 or 26 W.

*Summary of Mineral Prospect.*—As far as shown by exploration and exploitation up to the present time, paying ore has been found only in a small belt in northern Sevier county, and but one ore, stibnite, has been found in that district in paying quantities; though silver and lead ores have been found in small quantities. In speaking of stibnite as a paying ore, it is meant that it might be remunerative under more favorable conditions of transportation, smelting, etc. In the present state of things no reliable judgment could be given on the future of the antimony interest in this region. Whether the ores exist in quantity, or whether the richest deposits have already been exhausted, are questions that cannot be answered without a more thorough examination of the detailed geology of the antimony district than the State Survey could undertake. The output in 1890 was 54,188 pounds, but in August, 1892, none of the mines were being worked.

### *Commercial Stone.*

*Building Stone.*—It is possible that the ferruginous varieties of sandstones may prove of value as building stones: they dress easily and acquire a firm surface afterward, but on account of their brown color it is hardly probable that such stone, even though its wearing qualities be good, will ever be very popular.

There occasionally occurs locally a form of the sandstone, both pleasing in appearance, and, judging from weathered fragments, of good wearing quality. It is a slightly metamorphosed white or light gray sandstone, and varies from a sandstone hardly altered to an almost pure quartzite, the harder varieties, however, being too hard to work easily and therefore of less value. A typical outcrop occurs on Winfield creek, just below the junction of the east fork in 7 S., 21 W., section 10, northwest quarter. An outcrop on Antoine mountain in 6 S., 23 W., section 19, and one reported by Mr. Hopkins on Prairie creek in 7 S., 25 W., east of the centre of section 10, might be mentioned, and numerous other small outcrops were noted.

Considering the great extent of country to the south and east without building stone of any kind, it was hoped that stone of value would be found in this, the nearest of the rock-covered mountain country. At present rock is used here only for lining chimneys, the ferruginous sandstone and slabs of laminated sandstone being used for the purpose.

*Millstone Grit.*—Grits have been noted and described in preceding chapters. Rock of this kind is fairly abundant, but it is only here and there that it is firm enough to be used as millstones. Quite a number of these have been cut from it, several having come from the outcrop on top of the Chalybeate mountain just west of the Caddo river in 6 S., 20 W., section 14.

It is claimed by some that the meal ground with these stones is always gritty, and whether for that or some other reason, there are, as far as could be learned, none of the millstones running at present.

*Grindstones.*—A few attempts have been made to cut grindstones from the sandstone. None of these were seen, however, nor could it be learned just what kind of sandstone was used. Some stones were obtained from the part of the Chalybeate mountain east of the Caddo, whence that portion of the mountain took the name of Grindstone ridge. Similarly Grindstone creek, a tributary of Antoine creek in 8 S., 23 W., section 15, took its name from the occurrence there of a gritty sandstone from which grindstones have been made.

*Slates.*—The only places where slates give promise of any value is along the Rolling Fork in 6 S., 32 W.; and west of there near the State line, Owen reports good slate.[1] But it is doubtful if these have sufficient value to pay for working.

## XI. AGRICULTURE, ETC.

### *Soils.*

The soils of the region are of three kinds:

1. The red and brown soils of the overwash gravels.
2. The residuary soils formed by the decomposition of rocks in place.
3. The alluvial or river bottoms soils. These will be taken up in this order.

*The Overwash Soils.*—The overwash soils consist of gravel and sands with some clay. As shown by analysis, they are lacking in lime, and, over much of the region, the proportion of gravel to sand is so large as to make the land of little value with present modes of farming.

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[1] Owen, Second *Geol. Surv. of Ark.*, p. 112.

However, when the value of fertilizers becomes recognized, it is probable that this section, with its level yet well-drained areas, will form some of the most desirable agricultural land in the region.

At present a great forest of pine with some hard woods covers nearly the whole exposure of the overwash; there are but few farms and habitations on it at present.

*Residuary Soils.*—Residuary soils are those formed by the decomposition of the underlying rocks, and, as in this region these rocks are mostly sandstones, we have little else than sands with some clayey sands in the valleys.

Almost universally these soils have been enriched by the decaying leaves of the all-prevailing forest. This gives, when first cleared, considerable fertility, but as fertilizers are for the most part wholly unknown, or unthought of, this richness lasts but a few years. There is no doubt but that this soil, primarily rich, may, by proper care and the use of fertilizers, be made not only to maintain indefinitely its fertility, but even to become more productive with time. Proof of this exists in the very rare cases where some one does use fertilizers, with the result of every year raising twice as much to the acre as any of his neighbors, and each year leaving the land in better condition than the year before.

*Alluvial Soils.*—The alluvial soils form the bottom land along all the streams of any size. They are the cream of the agricultural lands. The reason for this is that they not only combine all the elements found in the other soils, but the rich vegetable mould, which in the residuary soils forms a layer on top, is here disseminated from top to bottom, so that they retain their fertility a long time. The idea so generally held that they will retain their fertility indefinitely is of course not correct.

The bottom lands are generally flooded lands upon which the river has for long periods deposited its load of silt and mud, until, having changed its course or deepened its channel, the land is left suitable for use. They are lacking in lime, as no lime is touched by the depositing streams. A few of them are still subject to overflow in highest water, which, to some extent, renews their fertility.

*Amelioration of Soils.*—Fortunately the work of Geological Survey has shown that in the Cretaceous region there are extensive deposits of gypsum, marls and chalks containing the elements needed by these sandy soils.[1]

The present methods of farming require that new clearings be frequently made and new fences built. The same amount of labor, expended in fertilizing, would increase crops, and increase the value of land.

### *Timber.*

Timber is at present the greatest latent source of wealth, and in consequence of the roughness of much of the region it will always play a considerable part in the sources of income. In the southern half of the region, where the Pleistocene gravel occurs, the timber is mostly pine; in some districts it is exclusively so, except in the creek bottoms. In the rest of the region both pine and hard wood are found, the latter being the more abundant and consisting largely of oaks.

This mountain timber is said not to be as even-grained as that growing in the bottoms, but has less sap and greater durability.

Of the oaks, the white oak is most abundant; red oak, post oak and others occur less frequently. The short-leafed pine is probably more abundant than any other single species of tree, especially over the gravel-covered area of the southeast, where magnificent forests of it are common. Sweet and black gum are plentiful in the southern and eastern part, and in the same part of the area is much holly. Cedar has been plentiful along the Cossatot and Rolling Fork; ash, hickory and many other valuable woods are well scattered over the region. As before stated, the whole area is one vast forest except for the few clearings made for cultivation.

At present, from lack of transportation facilities,[2] these forests have only a nominal value. But the timber near the railroad is being cut so rapidly that already the lumbermen are beginning to reach into this area. For this reason timber here has a prospective value sufficient to make it worthy of careful saving. At present it is treated in a most wasteful manner.

*Relation of Geology to Culture.*—The relation existing between the portions of a region under cultivation to the geology of the region is seldom more interestingly shown than in this area. The two factors in the geology are the shales and shaly sandstones and the structure which governs the exposures of these shaly layers. The shaly layers for a number of reasons being favorable for cultivation, the structure that brings the shales to the surface brings culture.

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[1] *Geol. Surv. of Ark.*, Rep. for 1888, Vol. ii, Chaps. xxii–xxvii.

[2] This report was written before the construction of the Kansas City, Pittsburg and Gulf Railway through the western part of Arkansas.—*J. C. Branner.*

If on a map of the region all the land under cultivation were shaded, it would be found that instead of being irregularly scattered, the shaded portions would run in belts, some narrow, others broad, while between them in several places would be belts of almost entirely unshaded territory, sometimes several miles broad, and from twenty-five to seventy-five miles long.

These broad belts of unsettled territory are frequently nearly level, or but slightly rolling, but they are mostly uplands. The one feature which distinguishes them is that they are outcrops of the great sandstone beds which form the upper portion of the columnar section of the Paleozoic strata of this area.

The strips of well-populated country run east and west, following the structure, and as they are almost exclusively confined to the valleys, the valley features of the topography will be briefly reviewed.

On the eastern sheet the largest valley is the Caddo valley, contained mostly in township 5 S., and running from the Ouachita river to the divide between the head waters of Antoine creek and the Little Missouri river. It is enclosed on the north by the Trap mountains and Brooks mountain, and on the south by the Chalybeate mountain and its continuation westward. Its main stream is the Caddo, and in it is contained the best farming land in the area, as well as the largest villages.

Notice the arrangement of the post-offices in this valley. On the Prairie Bayou anticline are Social Hill and Saunder's. South of them lie, in a line, Maddry, DeRoche, Bismarck, Valley, Point Cedar and Big Elm, not all on the same anticline, but on the major anticline.

At its western end the Caddo valley is broken into four minor valleys by three ridges: Rock Creek valley just north of Pine mountain; Antoine valley between Pine mountain and Big Bear mountain; Woodall valley between Big Bear mountain and Antoine mountain, and Walden valley between Antoine mountain and Straight and Wall mountains. The valleys in each case take their names from their main streams and are all well settled.

South of the Chalybeate mountain is a well-marked valley, known as the Chalybeate valley. This is wedge-shaped, with the point at Antoine creek in 6 S., 23 W., section 34, widening out to the east between the Chalybeate mountain and the high ridges in the north tier of sections of 7 S. At the eastern end it opens out and merges into the flat country in that direction. Its principal streams are those forming the head waters of the Terre Noir.

Caney Folk valley is an east and west valley a little further south. Starting from the head of Caney Fork of Antoine creek, 7 S., 24 W., section 7, it runs east, becoming lost in the level country north of Hollywood. From west to east it is bounded on the north by Wall mountain, Straight mountain and the ridges south of the Chalybeate valley, and on the south by the high east and west ridges which form the north edge of the old base level in the centre of 7 S., 21–24 W. It is followed all the way by the Arkadelphia-Murfreesboro road. In the area covered by the western sheet no such marked valleys occur. There are, however, a few belts, sometimes of indefinite limits and extent. They generally represent major anticlines, on which may be several minor anticlines. In these cases the folding as a whole is such that shales have been quite freely exposed, and it is along these belts that the land has been taken up and in which most of the settlements occur, so much so that, if the land under cultivation were indicated on the map, it would quite fairly outline these structural features as previously suggested.

Such a belt usually occurs just south of the novaculite ridges, as between Warm Spring and Brooks mountains on the north and Pine mountain on the south. It is indicated by the post-offices: Rock Creek, Wilson, Lodi, Langley, Port Logan and Ethridge. This is but an extension of the Rock Creek valley above mentioned.

The Antoine valley extension of the Caddo valley runs north of the Bear mountains and the Pine mountain in 6 S. To the north it extends toward the Pine mountain south of Rock creek. In the western part of 6 S., 27 W., the western extension of this valley is joined by a continuation of Woodall valley and then runs a little south of west. It is bordered on the north by White Oak creek and Silver Hill anticlinal axes, and on the south by Blue Ridge anticlinal axis and Cave Creek anticlinal axis. This belt follows the structure and shows the same lithological characters over the whole distance; in fact the same as those along the same strike to the Ouachita river. Kirby, Gentry, Star-of-the-West, New Hope and other settlements lie through the centre of this valley.

To the north of this belt the Brushy Branch anticlinal axis exposes shales and produces a low and well-inhabited area.

The Galena and Little Possum creek anticlines in like manner are not productive of strong topographic features and are well under cultivation.

*Water Power.*—Most of the larger streams carry some water all the year round. In the eastern part, however, the larger streams present but few opportunities for obtaining water power; though in a few places, as on the Caddo, where the stream makes a long and close bend or horseshoe, power might be obtained by carrying water over the neck at some narrow place.

In the western part the streams have more fall and opportunities for obtaining power are frequent. Many small mills and cotton gins exist there already. In many places the topography is such as to render the building of dams of twenty or thirty feet height, a comparatively simple problem. There are no falls of more than a few feet, unless the Falls of the Cossatot be counted such (the stream here drops between twenty and thirty feet by a series of small jumps in a space of less than a quarter of a mile), but in many places where ridges are cut through, the channel is narrow, giving facilities for building dams, while the fall is so rapid that but little land would be flooded by back water.

With the utilization of such cheap power there is no reason why cotton and other products, instead of going south to the railroads and then north to the mills, should not here be converted into cloth and other manufactured products.

*Mineral Springs.*—Several mineral springs have become quite well and favorably known as summer watering places for people from south Arkansas, Louisiana and Texas. The best known of these are:

Mineral Springs in 8 S., 22 W., section 18.
Jenkins' Springs in 6 S., 26 W., section 34.
Baker's Springs in 5 S., 30 W., section 14.
Gillam Springs in 4 S., 30 W., section 22.
Tyra Springs in 5 S., 32 W., section 2.
Bog Springs in 5 S., 32 W., section 10.

All of these springs are pleasantly located. At the present time the Mineral Springs in Clark county and Jenkins' Springs are the only ones much resorted to. The former is described in the Survey's report on mineral waters.[1]

Mineral Springs, Clark county, are two miles northeast of Antoine post-office, a quarter of a mile south of the military road, immediately on the Amity-Okolona road. Seven springs issue near each other and one larger spring a short distance away. These springs are well tiled and the large one has a cover. The water issues from a dark-colored, sandy deposit, with streaks of black shale or clay, all of which are probably of Cretaceous age. These beds dip to the south at an angle of 45°. The place is used as a local summer resort and camping place. An open Methodist Chapel, a dozen or more summer cottages and frames for a number of tents have been built at this locality.

The others have all been largely resorted to. For the past few years it has been claimed that there have been as many as five hundred people spending more or less of the summer at Baker's Springs. The principal constituents of these springs is given by Owen[2] as follows:

*Analysis of Baker's Sulphur Spring Water.*

"Carbonate of alkali, which is probably in the state of carbonate of soda.

"Chloride of sodium.

"A small quantity of free sulphuretted hydrogen.

"Traces of sulphate of soda and magnesia.

"When boiled down it exhibits strong alkaline properties. Its medical properties are a mild laxative; a diuretic, antiscorbutic, slightly alterative and strongly antacid. This spring rises from the slate at the base of a ridge of quartzose sandstone.

"There are also several other mineral springs in this neighborhood, in Polk county. One at Samuel Gray's on section 20, Township 5 north, Range 29 west, its temperature 58°, the air being 52° (also known as Shurd's Sulphur Spring, G. H. A.). The main characteristic constituents of this water are:

"Carbonate of soda.

"Chloride of sodium.

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[1] *Geol. Surv. of Ark.*, An. Rep. for 1891, Vol. i, p. 111.

[2] *Second Geol. Surv. of Ark.*, 1860, p. 97.

"Sulphuret of sodium.

"Traces of sulphate of soda.

"Traces of sulphate of magnesia.

"Its medical properties will be found to be analogous to those of Baker's Spring.

"Nathan Aldridge's Sulphur Spring contains the same constituents, only differing slightly in the proportions."

As shown in Pl. ii, these springs all rise from the same layer of shale.

The principal constituents of the Gap Springs are given by Owen as:

"Chloride of sodium.

"Sulphate of soda.

"Sulphate of magnesia.

"Bicarbonate of alkali.

"And probably a little sulphuret of alkali.

"A trace of carbonate of lime."

An examination of the so-called alum spring gave indications of the same ingredients, with the exception of the absence of sulphur, the presence of iron and a larger proportion of sulphates. These waters will have a mild, aperient effect, combined with a slight alterative action on the system."

Tyra springs in 5 S., 32 W., section 2, consist of a number of springs on the north bank of a small tributary of the Rolling Fork of Little river just west of Hatton Gap. The south bank and bed of the stream are novaculite, so that they appear to come from a layer of shale immediately overlying the novaculite.

Bog Springs are located in the pass of Cross creek through South or Bog mountain on the west side of the creek. They flow out from the foot of the mountain only a few yards from the creek. The principal spring forms a considerable bog.

As a rule, this area of Carboniferous rocks is well supplied with springs, and the streams are remarkably clear and the waters soft.

CONTRIBUTIONS TO BIOLOGY
FROM
THE HOPKINS SEASIDE LABORATORY
OF THE
LELAND STANFORD JR. UNIVERSITY.

XIII

# The Development of Glyphioceras and the Phylogeny of the Glyphioceratidæ.

BY

JAMES PERRIN SMITH.

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# PREFATORY NOTE.

This memoir is the thirteenth of a series designed to illustrate investigations and explorations connected with the Hopkins Seaside Laboratory, an adjunct of the biological laboratories of the Leland Stanford Junior University. These investigations have been carried on by means of the assistance given by Timothy Hopkins, Esq., of Menlo Park, California. The memoirs forming this series appear in the publications of the California Academy of Sciences, the present edition being a reprint.

OLIVER P. JENKINS,
CHARLES H. GILBERT,
*Directors Hopkins Laboratory.*

Date of publication, October 16, 1897.

# THE
# DEVELOPMENT OF GLYPHIOCERAS AND THE PHYLOGENY OF THE GLYPHIOCERATIDÆ.

BY JAMES PERRIN SMITH.

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## INTRODUCTION.

ALL modern classification is intended to be genetic, but in reality is usually not so, being based not on ontogenetic study, but rather on a comparison of supposed genetic series of adults. Much that has passed for demonstration has been in fact only conjecture. The only safe way is comparative study of ontogeny with series of adults—real phylogeny. This method of work is difficult to pursue with living forms, and still more so with fossils, although much that is good and reliable has been done with both.

The fossils that best lend themselves for this sort of work are the *Ammonoidea*, a group of cephalopods that lived from the beginning of the Devonian to the end of the Cretaceous. Being wholly extinct, the group is classified entirely by external markings, such as are capable of being preserved in

October 12, 1897.

fossils. Such marks are the sutures, the shape of the whorl, and surface ornamentation. Then, too, the ammonoids in growth envelop and protect the chambers of the earlier stages, thus preserving in a single individual a complete record of their larval history. By pulling off these outer coils the naturalist can obtain the shell in any desired stage, and can prevent the possibility of mistakes by selecting adults to start with. A study of the ontogeny of a fossil ammonoid may thus be carried on with as great accuracy as if the naturalist could hatch out and bring up the young animal in a marine laboratory.

Many authors have worked on the phylogeny of Mesozoic ammonites, and Hyatt has used especially the comparison of stages of growth of the individual with successive genera and species. But Mesozoic forms are so far from their origin that their ontogeny is long and the meaning of larval stages obscure. If we wish to learn the history of the race we must go back to the ammonoids of the Paleozoic, the goniatites. These forms, being nearer their origin, have shorter larval periods and go through fewer stages of growth; their interpretation is therefore simpler. Branco accumulated a considerable mass of exact data on the ontogeny of several goniatites, but without correlating these stages with genera. His figures are just as good and reliable as if he had done so; but since he was not looking for certain stages of growth, often the very ones we should like most to see have not been figured, due no doubt to lack of specimens. Karpinsky, in the same way, has worked out the ontogeny of *Pronorites* and *Medlicottia*, and the phylogeny of the *Prolecanitidæ*. Outside of this work the ontogeny of the goniatites is unknown, and they have been grouped together arbitrarily, often in contradiction to their true relationships. Probably so little work has been done in this line because of scarcity of specimens, especially such as can be taken apart to expose the larval stages. Paleozoic rocks have nearly everywhere been subjected to alteration and deformation, so that while species can be described from material found in them, it is rarely that one finds the inner whorls well preserved in cephalopods.

It was known to Quenstedt and L. von Buch that ammonites went through a goniatite stage in their youth; but these earlier paleontologists did not realize the importance and value of this fact, since they did not connect the idea with evolution, and hence they did not use their knowledge as a guide in classification. But we now know that the only way ever to work out the phylogeny of the ammonites is to study the development of the goniatites.

## CLASSIFICATION OF GONIATITES.

Beyrich[1] first recognized the unwieldiness of the old genus *Goniatites* and attempted to subdivide it as follows: 1. *Nautilini (Anarcestes* and *Mimoceras).* 2. *Simplices (Tornoceras, Brancoceras,* and *Prionoceras).* 3. *Aequales (Sporadoceras* and *Prolecanites).* 4. *Irregulares (Beloceras).* 5. *Primordiales (Gephyroceras).* 6. *Carbonarii (Glyphioceratidæ* p. p. *Glyphioceras* and *Gastrioceras).* This classification still holds sway, except in text-books of paleontology; for the genera and families into which later writers have divided the goniatites have not generally been accepted by paleontologists.

Afterward another classification was attempted by G. and F. Sandberger,[2] which agreed substantially with that of Beyrich, except in the names given to the groups. Neither the divisions of Beyrich nor of Sandberger were intended to represent genera or families, for they mostly contain heterogeneous elements; and even at that time the old genus *Ammonites,* comprising several times as many species as the goniatites, and very much more various in form, was still considered a unit.

The first attempt to distinguish genera among the goniatites was made by Dr. E. von Mojsisovics[3] in 1882, who named *Anarcestes, Aphyllites, Pinacites, Pronorites, Prolecanites,* and *Pericyclus,* and brought them into rather fanciful relationships to his genera of Triassic ammonites. The only systematic attempt to group all goniatites into genera and families is Hyatt's classification, "Genera of Fossil Cephalopods,"[1] where all known species were grouped into genera, and these in turn in five families: *Nautilinidæ*, Lower and Middle Devonian; *Primordialidæ*, Upper Devonian; *Magnosellaridæ*, Middle and Upper Devonian; *Glyphioceratidæ*, Upper Devonian, Carboniferous, and Permian; *Prolecanitidæ*, Upper Devonian, Carboniferous, Permian, and Trias.

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[1] Beitr. Kennt. Verstein. Rhein. Uebergangsgebirge. Abhandl. Berlin Akad. Wiss., 1837.

[2] Verstein. Rhein. Schichtensystems in Nassau.

[3] Cephalopoden d. Mediterranen Trias-Provinz.

Steinmann[2] groups the goniatites into two families supposed to be derived from the two chief genera of the *Nautilinidæ*, *Anarcestes*, and *Mimoceras*. On page 399 of his work is given a table showing the supposed genetic connection of the various genera and also their relationship to their ammonite successors of the Mesozoic. These relationships, however, are purely speculative, and not based on ontogenetic study of the groups.

Zittel in his later work[3] recognizes only two families, *Goniatitidæ* and *Prolecanitidæ*, of which the former comprises the *Nautilinidæ*, *Primordialidæ*, *Magnosellaridæ*, and *Glyphioceratidæ*. These subdivisions may then be retained with the rank of subfamilies.

### GLYPHIOCERATIDÆ *Hyatt.*

This group was established by Hyatt[4] to include a number of species from the Upper Devonian, Carboniferous, and Permian. The oldest genera are *Brancoceras* and *Prionoceras*, which began in the Upper Devonian, attained their acme in the Lower Carboniferous, and lived on into the Coal Measures. Both genera are smooth-shelled, and both have a pointed, undivided, ventral lobe, and two pairs of lateral lobes, of which the first is angular; the saddles of most species of both genera are broadly rounded, although on the type of *Prionoceras*, *Goniatites belvalianus* de Koninck, the first lateral saddles are angular. The only difference between the two genera is that *Brancoceras* is compressed, high-whorled, almost discoidal, and very involute; while *Prionoceras* is broad, low-whorled, and evolute. Hyatt considers *Brancoceras* as the radicle of the *Glyphioceratidæ*, and traces the group from *Anarcestes* of the Lower Devonian, through *Tornoceras (Parodiceras)* of the Middle Devonian. He admits the near relationship between the two genera, but considers *Prionoceras* as the link between the supposed radicle *Brancoceras* and *Glyphioceras*. The genealogy of the *Glyphioceratidæ*, according to Hyatt, is as follows:

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[1] Proc. Boston Soc. Nat. Hist., 1883, Vol. XXII.

[2] Elemente der Palæontologie, 1890.

[3] Grundzuege der Palæontologie, 1895.

[4] Proc. Boston Soc. Nat. Hist., Vol. XXII, p. 322.

$$\textbf{Anarcestes}\rightarrow\textbf{Tornoceras}\rightarrow\textbf{Brancoceras}\left\{\begin{array}{l}\textbf{Prionoceras}\rightarrow\textbf{Glyphioceras}\\ \textbf{Münsteroceras}\rightarrow\textbf{Gastrioceras}\rightarrow\textbf{Paralegoceras}\\ \textbf{Dimeroceras}\rightarrow\textbf{Pericyclus}\end{array}\right.$$

Professor K. A. von Zittel[1] has recently merged *Prionoceras* in *Brancoceras*, not even giving subgeneric rank to the former. But even though they may be nearly related, their phylogeny justifies the separation. Both genera undoubtedly branched off about the same time from *Tornoceras* in the Upper Devonian, but *Brancoceras* is not the radicle. While it is possible, although not known, that *Münsteroceras* may go through a *Brancoceras* stage, *Prionoceras* does not, neither does *Glyphioceras*. *Prionoceras* comes directly from *Tornoceras*, and in turn gives rise to *Glyphioceras*. It seems likely, too, that some species of *Gastrioceras* descended directly from *Prionoceras* by division of the ventral lobe, while others may have come from *Münsteroceras*. In any case, whether it came off from the radicle, or through *Münsteroceras*, *Gastrioceras* is a later branch than *Glyphioceras*, not being certainly known below the Coal Measures, and having its maximum in the Upper Coal Measures; it therefore deserves to rank as an independent genus. It also seems proper to retain *Prionoceras* and *Brancoceras* with full generic rank, and *Münsteroceras* as subgenus under *Glyphioceras*.

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[1] **Grundzuege der Palaeontologie, 1895, p. 398.**

## Genus **Glyphioceras** *Hyatt.*

This genus was established by Hyatt[1] to include Carboniferous species with semilunular whorls, usually broad and rather low; with divided ventral lobe, and a pair of angular lateral lobes; with the shell usually smooth, but in some cases with weak umbilical ribs; with periodic constrictions or varices. *Goniatites crenistria* Phillips (considered by many paleontologists as a synonym of *G. sphæricus* Martin, the type of the race of goniatites), was chosen as type of the genus. *Glyphioceras* was divided into two groups: The first with narrow umbilici, and no umbilical ribs at all, or only very weak ones; to this division belong *G. sphæricum* Martin, *G. crenistria* Phillips, and many others. The second group contains species with wider umbilici, and often with strong umbilical ribs; to this group belong *G. diadema* Goldfuss, and several others. Zittel[2] emended the genus, and included in it *Münsteroceras*, *Nomismoceras*, and *Homoceras*. Karpinsky[3] afterward attempted to show that *Glyphioceras* and *Gastrioceras* grade over into each other, and that there is no reason for retaining the two as independent genera. But just this same thing might be said of any two nearly related genera. There is certainly no difficulty in distinguishing typical members of both groups; and since *Gastrioceras* is a later branch than *Glyphioceras*, it facilitates phylogenetic study to consider them as distinct. As thus emended and restricted, *Glyphioceras* contains species from the Carboniferous, ranging from the Waverly horizon, goniatite-beds of Rockford, Indiana, the very base of the system, up into the Permian.

Little work has been done on the phylogeny of this genus, notwithstanding its importance as the chief member of the Carboniferous ammonoids and the type of the whole race of goniatites. The first observations were made by Hyatt[4], who figured a larva of *Glyphioceras diadema* Goldfuss, consisting of the protoconch with two-thirds of the first whorl attached. Branco[1] afterward figured the protoconch and two larval stages of *G. diadema* at diameters of 0.66 mm., and 0.90 mm. respectively. He noted, too, that on this species the ventral lobe became divided at a diameter of six millimetres, although his figure I, on Plate IV, shows the ventral lobe broadening and preparing for division at diameter of 2.25 mm. But the consecutive larval stages were not figured and described, nor were they compared with known genera, although that does not lessen the value of his data.

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[1] Proc. Boston Soc. Nat. Hist., Vol. XXII, p. 328.

[2] Handbuch der Palæontologie, Abtheil I, Band II, p. 420.

[3] Mém. Acad. Sci. St. Petersbourg, Tome XXXVII, No. 2. Ammoneen der Artinsk-Stufe, p. 46.

[4] Bull. Mus. Compar. Zoöl., Vol. III, 1872, No. 5, Pl. II, figs. 3 and 4.

Hyatt in his "Genera of Fossil Cephalopods" often compares the larvæ of this group of goniatites to their ancestral genera, but as the paper is not accompanied by illustrations and systematic descriptions of stages of growth of the species cited, it is not easy to follow the correlations. It was therefore desirable that some typical species of *Glyphioceras* should be studied in detail from the protoconch upwards, and material suitable for this was found in *G. incisum* Hyatt, from the Fayetteville shale, Warsaw division of the Lower Carboniferous, at Moorefield, Independence County, Arkansas.

### Glyphioceras incisum *Hyatt.*

PLATES XIII-XV.

*Glyphioceras incisum* HYATT, Geol. Surv. Texas, Fourth An. Report, p. 471, Pl. XLVII, figs. 44-48.

The form is globose, broad, low-whorled, with semilunular cross-section, and very involute; in the adult the umbilicus is closed so that the inner whorls are concealed. The abdomen is broadly rounded and slightly flattened, while the umbilical shoulders slope steeply inwardly. There are four or five constrictions to a whorl, visible both on the shell and on the cast. These occurred even in the early larval stages, beginning at a diameter of 0.90 mm., and lasting until old age.

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[1] Palæontographica, Vol. XXVII. Beiträge z. Entwick. Foss. Ceph., Pl. IV, fig. 1.

The shell is marked with distinct cross striæ of growth, with fine sharp crenulations, which show only toward maturity. The elevations between the pits of the crenulations become in the adult indistinct spiral ridges, giving a finely reticulated aspect to the surface. The cross striæ and spiral ridges are not visible on the cast. In the adult stage the surface is ornamented with undulating growth bands, forming weak ribs strongest near the umbilicus and distinctly visible on the cast. These originate from bundling of the cross striæ at the umbilicus, and give the shell a decided resemblance to the Triassic genus *Juvavites*, which may very possibly be a descendant of *Glyphioceras*. This bundling begins at about 2.3 mm. diameter.

The visible sutures consist of a pair of pointed ventral lobes (divided by a notched saddle) and a pair of angular lateral lobes. All the lobes and the first pair of lateral saddles are angular in the adult, while the second pair of saddles is broadly rounded. A second pair of lateral lobes is on the umbilical shoulders, just concealed by the involution. The internal sutures consist of a pointed antisiphonal or dorsal lobe, and a pair of similar lateral lobes. In the early part of the adult stage the lateral saddles are rounded, as shown on Pl. XV, fig. 11, on a specimen of 15 mm. diameter. In the youthful stages all the saddles are broad and the lobes only slightly pointed.

MEASUREMENT OF SPECIMENS OF ADULT AGE.

| | mm. | mm. | mm. | mm. |
|---|---|---|---|---|
| Diameter ..... | 15.00 | 20.7 | 23.00 | 31.5 |
| Height of last whorl ....... | 7.25 | 8.2 | 12.5 | 17.0 |
| Height of last whorl from the preceding. | 4.00 | 4.0 | ........ | ........ |
| Width of last whorl ....... | 12.00 | 15.7 | 20.5 | 24.5 |
| Involution ..... | 3.25 | 4.2 | 7.5 | ........ |
| Width of umbilicus ....... | 1.70 | ........ | ........ | ........ |

*Position and Locality.*—*Glyphioceras incisum* was found in the Fayetteville shale, Warsaw division of the Lower Carboniferous, at Moorefield, Independence County, Arkansas, accompanied by *Nautilus (Endolobus) spectabilis* Meek, *Productus semireticulatus* Martin, *P. cora* d'Orbigny, *Spirifer lineatus* Martin, *S. glaber* Martin, *Terebratula bovidens* Meek, and numerous other less characteristic species. The specimens of *G. incisum* from the Moorefield beds agree exactly with those described by Hyatt from the Bend formation, Carbonferous, five miles west of Lampasas, Texas. In the same paper Hyatt[1] describes *Glyphioceras cumminsi*, also from the Bend formation; he compares *G. cumminsi* to *G. striatum* Sowerby and *G. crenistria* Phillips, finding, however, points of difference from both. European paleontologists now regard *G. striatum* and *G. crenistria* as synonymous, and many go so far as to place both as synonyms under *G. sphæricum* Martin. To this last species Hyatt compares *G. incisum*, but finds that *G. incisum* lacks the crenulations which *G. sphæricum* has, and agrees with it in lacking spiral ridges. *G. incisum* is certainly very nearly related to *G. sphæricum*, and if the European forms *G. crenistria* and *G. striatum* are all identical with *G. sphæricum*, the American form might also very well be classed as a variety under that species, especially as *G. incisum* as an adult has distinct crenulations. The European Carboniferous faunas are turning out to be much more closely related to those of the Mississippi Valley than has been recognized heretofore. In a recent paper the writer[2] has described from the Coal Measures of Arkansas the following European Coal Measure forms not before known in America: *Conocardium aliforme* Sowerby, *Gastrioceras marianum* Verneuil, *Pronorites cyclolobus* Phillips, besides many others known before in America. Thus the presumption is not against the identity of very similar forms in the two regions, but rather in favor of it.

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[1] Op. cit., p. 467, Pl. XLVII, figs. 33-43.

[2] Proc. Am. Phil. Soc., Vol. XXXV, 1896, No. 152, "Marine Fossils from the Coal Measures of Arkansas."

## LARVAL STAGES.

In order to obtain the larval stages of *Glyphioceras incisum*, a number of adults were selected, so as to make sure of the identity, and the outer coils were broken off until the desired size was obtained. This necessitated the destruction of several specimens, but was well worth while in view of reliability of the results. The specimens were studied in three different mountings, dry on card-board, in a drop of water on card-board, and in water in a watch-glass over a strong condensing lens. In the first way the surface markings are seen best, in the second the sutures and form, in the third the internal structure when the specimen is translucent. The nomenclature used is that of Hyatt, published in "Phylogeny of an Acquired Characteristic."[1]

*Phylembryonic.* The protoconch represents the first shell secreted by the shell-gland, and must have been formed while the animal was in the egg. It is quite possible that some of the chambers were formed before the egg was hatched, but this cannot be determined on fossils. The protoconch is taken for convenience to represent the phylembryonic stage of growth, the end of the embryonic, when the class or phylum can be determined, and the animal is already a cephalopod. In shape, the protoconch is a smooth, rather elongate, bobbin-shaped, oval body, of which the upper part projects forward in a lap, where the first chamber was joined to it. The protoconch was not the whole of the embryo chamber, for a part of the spiral tube must have furnished a lodging for the embryo; but after the formation of the first air-chamber it is no longer possible to determine how long the primitive body-chamber was. The protoconch corresponds to the primitive nautilian shell from which the ammonoids descended, but the parallelism is not exact, for the initial chamber of the nautiloids is not calcareous, while acceleration of development has pushed back to the embryo the calcareous shell of the ammonoids.

In the protoconch is seen the beginning of the siphon, or siphonal *cæcum*, a pear-shaped knob, projecting a short distance into the embryonic shell. It must have been present in the embryo, for it is older than the first suture, but its function is unknown. In some specimens what seemed to be a tube could be seen attached to the *cæcum;* this is probably the prosiphon described by Munier-Chalmas, but no specimens sufficiently definite to figure could be obtained.

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[1] Proc. Am. Phil. Soc., Vol. XXXII, No. 143.

On Pl. XIII, figs. 1 and 2, is shown the protoconch from which all the chambers have been broken off. Dimensions:

| | mm. |
|---|---|
| Diameter | 0.46 |
| Height of whorl at attachment of first chamber | 0.24 |
| Height of first chamber from protoconch | 0.17 |
| Width | 0.66 |
| Involution | 0.07 |

The protoconch is constant in size and dimensions, for several specimens were obtained free from the air-chambers. Also a number of others were broken back almost to the protoconch, and the dimensions agreed, as nearly as could be determined.

On Pl. XIII, figs. 3, 4, and 5, is shown the protoconch of a *Glyphioceras* from the Carboniferous of Scott County, Arkansas, 2 N., 29 W., section 36, near the center. This species was compared by the writer[1] to *G. sphæricum* Martin, and said to be identical with the species from Moorefield. But although the adults are nearly alike, the protoconchs are quite unlike, as may be seen by a comparison of the two figures. The following are the dimensions of the Scott County form:

| | mm. |
|---|---|
| Diameter | 0.53 |
| Height of whorl at attachment to the protoconch | 0.26 |
| Height of whorl from the protoconch | 0.18 |
| Width | 0.80 |
| Involution | 0.08 |

These figures show it to be larger and proportionally broader than the typical *G. incisum.* If the species are identical then this is an unusual variation.

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[1] "Marine Fossils from the Coal Measures of Arkansas," p. 11.

*Ananepionic.* As soon as the first air-chamber is formed the animal has left the embryonic and begun the larval stage, and then takes rank with the chambered nautiloids. The suture at this stage consists of a very broad ventral saddle with a pair of narrow lateral lobes. On Pl. XIII, fig. 1, is shown this suture; fig. 6 shows this and also the second chamber-wall; figs. 9 and 10 show the ananepionic suture with half a coil attached. Pl. XV, fig. 1, shows the initial suture along with the later ones. While this stage cannot be compared to any particular genus, it corresponds to some nautilian form of the Silurian. The ananepionic siphon is about half-way between the dorsum and the venter, in this character, too, agreeing with the nautiloids. Where the siphon passes through the partition the wall is bent backward in a cone and has a siphonal collar around the tube. The surface is still smooth, no ornamentation of any sort ever having been seen on early stages of ammonoids.

*Metanepionic.* With the second larval substage the shell becomes a true ammonoid; this begins with the second suture, which takes on the ventral lobe of the goniatites. The shell is smooth as before, and the whorl changes little in shape, being still low, broad, and little embracing. The sutures and shape correspond exactly to *Anarcestes*, the primitive goniatite and radicle of the ammonoids. *Anarcestes* was named but not characterized by Mojsisovics,[1] and afterward defined by Hyatt[2] as containing forms with smooth, broad, and low whorls, with semilunular cross-section, deep umbilicus, and rather broad abdomen. *Goniatites subnautilinus* Schlotheim, of the Middle Devonian, was chosen as type of the genus, but most of the species occur in the Lower Devonian, in the Hercynian beds, which were formerly assigned to the Upper Silurian.

*Glyphioceras incisum* shows the *Anarcestes* stage at the second and third sutures, and resembles closely *A. lateseptatus* Beyrich of the Lower Devonian. On Pl. XIII, fig. 6, is seen the transition from the ana- to the metanepionic;

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[1] "Cephalopoden der Mediterranen Trias-Provinz," p. 181.

[2] "Genera of Fossil Cephalopods," p. 309.

figs. 9 and 10 show the transition from ananepionic (first suture) to metanepionic (second and third sutures); figs. 11 and 12 show the *Anarcestes* stage at the first and second sutures visible on the whorl. The metanepionic sutures, seen in projection on Pl. XV, figs. 2 and 3, consist of a deep, rounded, ventral lobe, and a pair of broad, shallow, lateral lobes. When the animal has progressed thus far in its development it is a true goniatite, and the siphon has already turned to the outside of the whorl, or abdomen. On Pl. XV, fig. 12, are shown for comparison the sutures of *A. subnautilinus* (after L. von Buch, Gesammelte Werke, Vol. IV, p. 116, Pl. XI, fig. 9).

*Paranepionic.* When the broad lateral lobes become indented with a pair of lateral saddles, the sutures, the narrow umbilicus, and the broad, low whorl all correspond to *Tornoceras* Hyatt, of the Middle and Upper Devonian. *G. incisum* reaches this stage at the fourth suture, at a diameter of about 0.68 mm., one-third of a whorl, and continues in it for the fourth, fifth, and sixth sutures, up to a diameter of 0.80 mm., and five-eighths of a whorl. Pl. XIII, figs. 9 and 10, shows the form at the *Tornoceras* stage, at one-half a whorl, with the following dimensions:

| | mm. |
|---|---|
| Diameter | 0.74 |
| Height last coil | 0.38 |
| Height last coil from the protoconch | 0.13 |
| Width of last whorl | 0.77 |
| Involution | 0.26 |
| Width of umbilicus | 0.06 |

On Pl. XIII, figs. 11 and 12, the *Tornoceras* stage shows at the fourth, fifth, and sixth sutures.

*Neanic.* When the ammonoid in its growth no longer shows the characters of its distant ancestors, but has already taken on those of its own family, it may be said to have left the larval stage proper and to have begun its youth. The ananeanic is then the beginning of the adolescent period. *G. incisum* at the seventh suture, three-fourths of a whorl, and diameter of 0.85 mm., changes its form markedly; the two pairs of lateral lobes become more pronounced, and the ventral lobe becomes smaller in proportion; the coil leaves its close spiral and shows decided egression, the umbilicus becomes wider, while the chamber becomes actually narrower than in the *Tornoceras* stage, as seen from these figures: width of chamber at diameter 0.74 mm. is 0.77 mm., at diameter 0.92 mm. it is 0.69 mm. The involution also becomes less. At diameter 0.90 mm. and end of the first whorl a decided constriction, marking a temporary mouth of the shell, makes its appearance. This stage corresponds to the Upper Devonian and Carboniferous genus *Prionoceras* Hyatt,[1] of which *P. divisum* Muenster, of the Upper Devonian, and *P. belvalianum* de Koninck, of the Lower Carboniferous, are the types. These species have broad, low, rather evolute whorls, with wide umbilici and smooth surfaces, ornamented only with periodic constrictions. The external sutures consist of an undivided, pointed, ventral lobe, one pair of angular lateral lobes, and a second pair of rounded lobes on the umbilical border. The external saddles are angular and the lateral saddles rounded and broad. To this genus may also be assigned *Goniatites compactus* Meek and Worthen, Geol. Survey Illinois, Vol. V, p. 611, Pl. XXXI, fig. 2, of the Coal Measures; and *G. greencastlensis* Miller and Gurley, Bull. XI, Illinois State Mus. Nat. Hist., p. 44, Pl. V, figs. 12–14, from the St. Louis group of the Lower Carboniferous. These species differ from the types in the rounded external saddles, but in this respect they agree with the ananeanic substage of *G. incisum*. The beginning of the *Prionoceras* stage is shown on Pl. XIII, figs. 11 and 12, in the widening of the umbilicus, egression of the spiral, and narrowing of the chamber. Dimensions of the specimen:

| | mm. |
|---|---|
| Diameter | 0.92 |
| Height of last whorl | 0.33 |
| Height of last whorl from the preceding | 0.23 |
| Width of last whorl | 0.69 |
| Involution | 0.10 |
| Width of umbilicus | 0.30 |

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[1] "Genera of Fossil Cephalopods," p. 328.

This stage begins at 0.85 mm. diameter, three-fourths of a whorl from the protoconch, and lasts with little change except increase in size for two revolutions up to a diameter of 2.25 mm., when the transition to *Glyphioceras* begins.

Plate XIV, figs. 1 and 2, shows a continuation of the *Prionoceras* stage, at one and three-fourths whorls, with dimensions:

| | mm. |
|---|---|
| Diameter | 1.29 |
| Height of last coil | 0.45 |
| Height of last coil from the preceding | 0.29 |
| Width of last coil | 0.95 |
| Involution | 0.15 |
| Width of umbilicus | 0.50 |

On this specimen are seen two constrictions about two-thirds of a revolution apart, thus making the resemblance to *Prionoceras* very striking. At this stage are first seen the cross striæ of growth. A continuation of the same generic stage is shown on Pl. XIV, figs. 3 and 4, at one and seven-eighths whorls, and dimensions:

| | mm. |
|---|---|
| Diameter | 1.38 |
| Height of last coil | 0.52 |
| Height of last whorl from the preceding | 0.31 |
| Width of last whorl | 1.02 |
| Involution | 0.21 |
| Width of umbilicus | 0.51 |

The relative dimensions are nearly the same as at diameters 0.92 mm. and 1.29 mm., but the sutures differ slightly, the ventral lobe being slightly blunted, as shown on Pl. XV, fig. 8. On this specimen only one constriction was visible at diameter of 0.85 mm.

On Pl. XIV, figs. 5 and 6 show a larger specimen still in the *Prionoceras* stage, at two and one-eighth whorls. Dimensions:

| | mm. |
|---|---|
| Diameter | 1.64 |
| Height of last whorl | 0.60 |
| Height of last whorl from the preceding | 0.40 |
| Width of last whorl | 1.38 |
| Involution | 0.20 |
| Width of umbilicus | 0.54 |

No constrictions were visible on this specimen; that one which occurs at end of the first whorl being concealed by the outer coil. The relative dimensions are nearly the same as on the preceding specimens, except that the last whorl is proportionally broader and the umbilicus narrower. The sutures are the same as on the last specimen. The end of the *Prionoceras* stage is shown on Pl. XIV, figs. 7 and 8, at two and three-fourths of a whorl. Dimensions:

| | mm. |
|---|---|
| Diameter | 2.25 |
| Height of last whorl | 0.87 |
| Height of last whorl from the preceding | 0.50 |
| Width of last whorl | 1.82 |
| Involution | 0.37 |
| Width of umbilicus | 0.58 |

No constrictions were visible on this specimen, the earlier ones being concealed by the outer whorl. The figures show that the relative dimensions remain nearly as before, but the umbilicus becomes considerably narrower. The sutures are like those of the smaller specimens, but on the last half-whorl the ventral lobe becomes very much flattened, and at diameter of 2.2 mm. becomes slightly indented by the beginning of a ventral saddle, thus showing a transition to *Glyphioceras*, and the end of the adolescent stage. No youthful stages larger than this were successfully broken out in condition to figure, but the imperfect ones obtained showed a gradual narrowing of the umbilicus and increase in height of the whorl and involution.

### ADULT STAGE.

The form of the adult *Glyphioceras incisum* has already been sufficiently described in this paper and in Hyatt's monograph. The sutures changed in increasing depth of the ventral sinus and sharpening of the lateral lobes, as shown on Pl. XV, fig. 11, taken from a specimen of diameter of 15 mm. The early adult sutures have been figured by Hyatt, Geol. Survey Texas, Fourth An. Rep., Pl. XLVII, figs. 44–45.

Plate XIV, fig. 9, shows the smallest specimen obtained of the adult stage; it agrees in all essentials with those of larger growth, only the ventral saddle is shorter and the lateral saddles more rounded.

## TABLE OF STAGES OF GROWTH.

| | Proto-conch. | Proto-conch and two chambers. | One-half whorl, *Anarcestes* to *Tornoceras* | First whorl, *Tornoceras* to *Priono-ceras.* | *Priono-ceras* stage 1¾ whorls | *Priono-ceras* 1⅞ whorls. | *Priono-ceras* 2⅛ whorls. | *Priono-ceras* 2⅜ whorls. |
|---|---|---|---|---|---|---|---|---|
| | mm. | mm. | mm. | mm. | mm | mm. | mm. | mm. |
| Diameter........ | 0.46=1.00 | 0.61=1.00 | 0.74=1.00 | 0.92=1.00 | 1.29=1.00 | 1.38=1.00 | 1.64=1.00 | 2.25=1.00 |
| Height of last whorl.......... | 0.24=0.52 | 0.31=0.50 | 0.38=0.52 | 0.33=0.35 | 0.45=0.34 | 0.52=0.38 | 0.60=0 36 | 0.87=0.38 |
| Height of last whorl from the preceding .... | 0.17=0.36 | 0.15=0.24 | 0.13=0.17 | 0.23=0.25 | 0.29=0.22 | 0.31=0.22 | 0.40=0.23 | 0.50=0.22 |
| Width of last whorl.......... | 0.66=1.56 | 0.66=1.08 | 0.77=1.04 | 0.69=0.75 | 0.95=0.73 | 1 02=0.73 | 1.38=0.84 | 1.82=0.80 |
| Involution...... | 0.07=0.15 | 0.16=0.26 | 0.26=0.35 | 0.10=0.10 | 0.15=0.11 | 0.21=0.15 | 0.20=0.12 | 0.37=0.16 |
| Width of umbilicus........... | ...... ... | .......... | 0.06=0.08 | 0.28=0.30 | 0.50=0.38 | 0.51=0.37 | 0.54=0.32 | 0.58=0.25 |

| | *Prionoceras* to *Glyphioceras.* | *Prionoceras* to *Glyphioceras.* End of neanic. | *Glyphioceras.* Anephebic. | *Glyphioceras* |
|---|---|---|---|---|
| | mm. | mm. | mm. | mm. |
| Diameter.................... | 2.60=1.00 | 3.00=1.00 | 6.00=1.00 | 11.00=1.00 |
| Height of last whorl............. | 1.24=0.47 | 1.45=0.48 | 3.50=0.58 | 5.50=0.50 |
| Height of last whorl from the preceding.. | 0.76=0.29 | 0.83=0.27 | 1.80=0.30 | 3.00=0 27 |
| Width of last whorl ............. | 2.32=0.88 | 2.82=0.94 | 6.00=1 00 | 10.00=0.90 |
| Involution.................. | 0.48=0.18 | 0.62=0.20 | 1.65=0.27 | 2.50=0.22 |
| Width of umbilicus............. | 0.61=0.23 | 0.66=0.22 | 0.90=0.15 | 1.00=0.09 |

## SUMMARY OF RESULTS.

The ontogeny of *Glyphioceras* is of interest not only for its own sake, but also because it is the most important genus of the largest family of ammonoids of the Carboniferous, and because this family gave rise to a large part of the ammonites of the Trias. *Glyphioceras* in its ontogeny goes through the following stages: phylembryonic, protoconch, representing the primitive cephalopod; ananepionic, Silurian nautiloid; metanepionic, *Anarcestes* of Lower Devonian; paranepionic, *Tornoceras* of Middle Devonian; neanic, *Prionoceras* of Upper Devonian and Carboniferous, showing gradual transition through ana-, meta-, and paraneanic, and a gradual change from *Prionoceras* to *Glyphioceras* in the late adolescent and early adult stages. *Prionoceras* is undoubtedly the family radicle, and *Brancoceras* is a side-branch, since *Glyphioceras* does not go through any stage corresponding to the latter genus. *Gastrioceras* comes from *Prionoceras* (through *Münsteroceras)* by somewhat narrowing the whorl and division of the ventral lobe. *Glyphioceras* comes directly from *Prionoceras* by narrowing the umbilicus so as to conceal most of the inner whorls and by division of the ventral lobe.

The division of the subfamily *Glyphioceratidæ* into *Brancoceras*, *Prionoceras*, *Pericyclus*, *Glyphioceras*, (subgenus *Münsteroceras)*, *Gastrioceras*, *Paralegoceras*, is quite proper for phylogenetic reasons.

According to Steinmann the *Ceratitidæ* of the Trias are descended from *Gastrioceras*, and the *Tropitidæ* from *Pericyclus*, but neither of these groups goes through stages of growth corresponding to these genera. *Tropites* does, however, go through a *Prionoceras* stage, and later it resembles closely *Gastrioceras*, but it already has the *Tropites* keel before the ventral lobe is divided. It then descends from the *Glyphioceratidæ*, but directly from the radicle and not through any modified form. But it is quite likely that some of the genera assigned to the *Tropitidæ* do descend directly from other members of the *Glyphioceratidæ*.

LELAND STANFORD JUNIOR UNIVERSITY,
CALIFORNIA,
October, 1897.

## EXPLANATION OF THE FIGURES.

### PLATE XIII.

**All figures on this plate are forty times enlarged.**

*Glyphioceras incisum* HYATT.

Figs. 1, 2. Protoconch. 1, from above; 2, from front. Diameter 0.46 mm.

Figs. 3, 4, 5. Protoconch of same or a nearly related species from Scott County, Arkansas. 3, from above; 4, from front; 5, from side.

Figs. 6, 7, 8. Protoconch with first two sutures. 6, from above; 7, from front; 8, from side.

Figs. 9, 10. Larval stage, diameter of 0.74 mm., protoconch and one-half of first whorl, showing the first four sutures, from phylembryonic to the paranepionic substage. 9, from side; 10, from front.

Figs. 11, 12. Larval stage, diameter of 0.92 mm., first whorl, showing first eight sutures, and transitions from the metanepionic (*Anarcestes* stage), through paranepionic (*Tornoceras* stage) to ananeanic (*Prionoceras*) stage. 11, from front; 12, from side.

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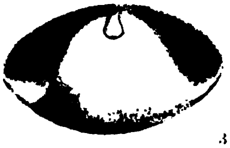

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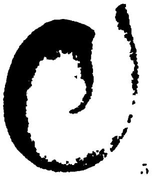

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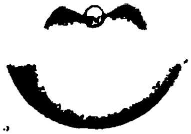

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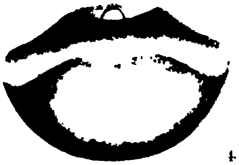

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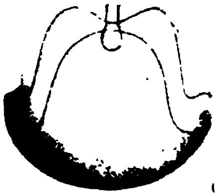

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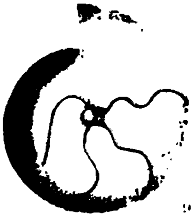

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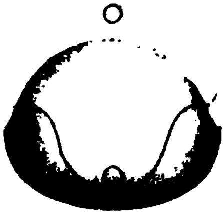

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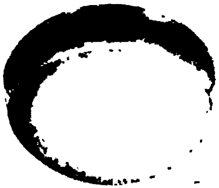

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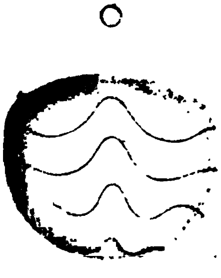

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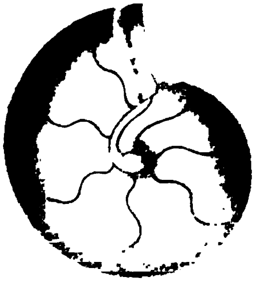

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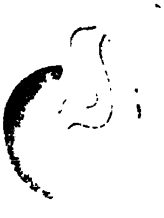


## EXPLANATION OF THE FIGURES.

### PLATE XIV.

All figures on this plate are twenty times enlarged, except fig. 9, which is twice natural size.

*Glyphioceras incisum* HYATT.

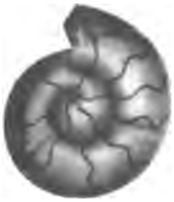
Figs. 1, 2. Adolescent stage, one and three-fourths whorls, diameter of 1.29 mm., last whorl is ananeanic (*Prionoceras* stage) and shows transition from paranepionic. 1, front; 2, side.

Figs. 3, 4. Adolescent stage, diameter of 1.37 mm., one and seven-eighths whorls, *Prionoceras* stage. 3, from front; 4, from side.

Figs. 5, 6. Adolescent stage, diameter of 1.64 mm., two and one-eighth whorls, *Prionoceras* stage. 5, from front; 6, from side.

Figs. 7, 8. End of adolescent stage, diameter of 2.25 mm.; two and three-fourths whorls; transition from *Prionoceras* to *Glyphioceras* in the division of the ventral lobe, and beginning rounding of the whorl. 7, side view; 8, front view.

Fig. 9. Early adult stage, diameter of 15 mm., twice enlarged.



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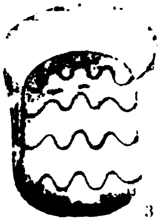

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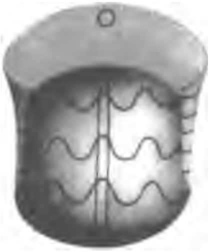

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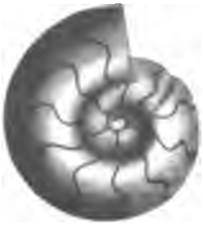

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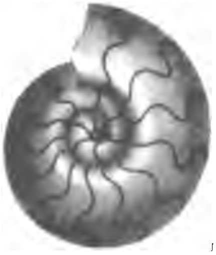

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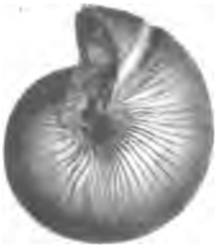

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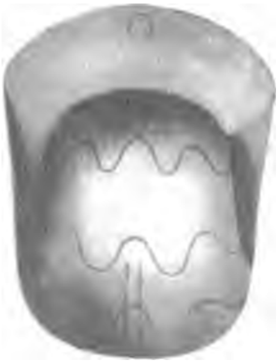

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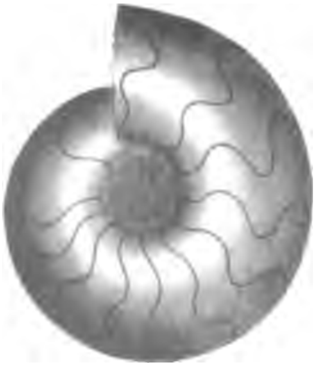


## EXPLANATION OF THE FIGURES.

### PLATE XV.

All figures of *Glyphioceras* on this plate are magnified forty times, except fig. 11, which is four times enlarged.

### *Glyphioceras incisum* HYATT.

Fig. 1. First suture, ananepionic.

Fig. 2. Second suture, metanepionic (*Anarcestes*).

Fig. 3. Third suture, metanepionic.

Fig. 4. Fourth suture, paranepionic (*Tornoceras*).

Fig. 5. Fifth suture, at one-half a revolution, and diameter of 0.74 mm., paranepionic.

Fig. 6. Eighth suture, at one revolution, and diameter of 0.92 mm., ananeanic (*Prionoceras*).

Fig. 7. Suture at one and three-fourths revolutions, and diameter of 1.29 mm., ananeanic.

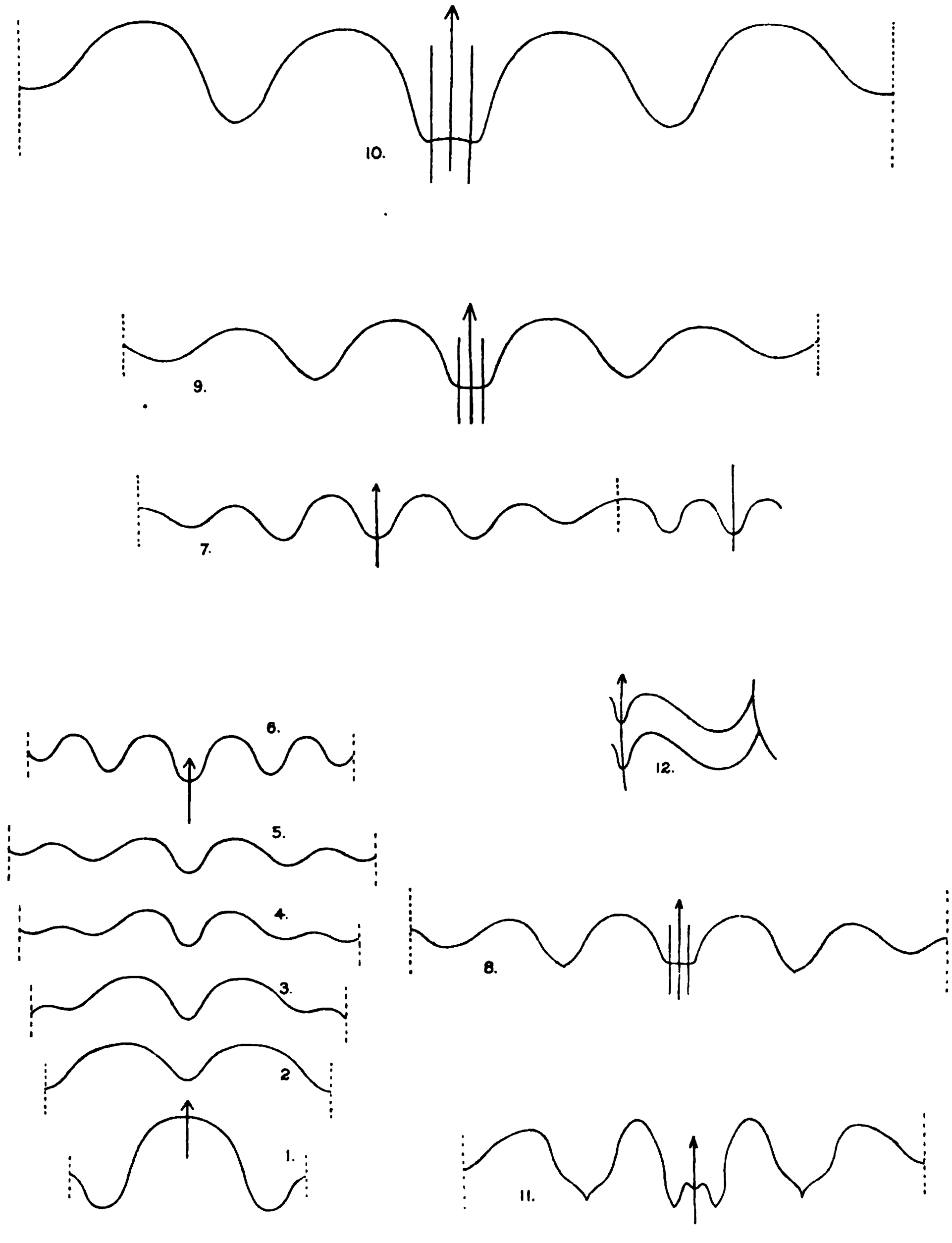
Fig. 8. Sutures at one and seven-eighths revolutions, and diameter of 1.37 mm., (*Prionoceras*).

Fig. 9. Sutures at two and one-eighth revolutions, and diameter of 1.64 mm., (*Prionoceras*).

Fig. 10. Sutures at diameter of 2.25 mm., 2½ whorls, transition from *Prionoceras* to *Glyphioceras*.

Fig. 11. Sutures at diameter of 15 mm., adult.

Fig. 12. Sutures of *Anarcestes subnautilinus*, after L. von Buch, Gesammelte Werke, Vol. IV, p. 116, Pl. XI, fig. 9.



GLYPHIOCERAS INCISUM HYATT.

LITH. BRITTON & REY S.F.

LELAND STANFORD JUNIOR UNIVERSITY PUBLICATIONS.

CONTRIBUTIONS TO BIOLOGY
FROM
THE HOPKINS SEASIDE LABORATORY.

XIV.

# A Geological Reconnaissance of the Coal Fields of the Indian Territory.

...BY...

NOAH FIELDS DRAKE, PH.D.

Reprint from the Proceedings of the American Philosophical Society.
Vol. xxxvi, No. 156.

LELAND STANFORD JR. UNIVERSITY
PALO ALTO, CALIFORNIA,
1898.

# Prefatory Note.

This memoir is the fourteenth of a series designed to illustrate the investigations and explorations of the Hopkins Seaside Laboratory, an adjunct of the biological laboratories of the Leland Stanford Junior University. The series is issued under the patronage of Timothy Hopkins, Esq, of Menlo Park, California. The present paper is published by the American Philosophical Society, appearing simultaneously in its present form and as a part of the Proceedings of that Society.

CHARLES H. GILBERT,
OLIVER P. JENKINS,
*Editors*.

DATE OF PUBLICATION: JANUARY 25, 1898.

LELAND STANFORD JUNIOR UNIVERSITY PUBLICATIONS.

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1898.

# A GEOLOGICAL RECONNAISSANCE OF THE COAL FIELDS OF THE INDIAN TERRITORY.[1]

BY NOAH FIELDS DRAKE.

(*Read September 3, 1897.*)

## INTRODUCTION.

During the spring, summer and fall of 1896, the writer spent six months making a geological reconnaissance of the larger part of the Coal Measures and adjacent formations of the Indian and Oklahoma Territories. The best maps that could then be had of the region were exceedingly inaccurate. In connection with geologic observations, sketch maps were therefore made of areas that were especially important. Nearly all the area south and east of the Canadian river, shown on the accompanying map, was sketched and studied rather closely, partly because the coal beds of that area are valuable economically, and partly because the folded structure and the resulting topography are of special geologic interest. The bordering areas of the Boone chert and limestones were studied because these beds have a wide distribution, and a knowledge of their relations to overlying beds was essential to an understanding of the structure of the area and of the conditions of deposition.

---

[1] A thesis for the degree of Doctor of Philosophy, presented to the Department of Geology of the Leland Stanford, Jr., University, May, 1897.

## PART I.

### STRUCTURAL GEOLOGY.

*Area of the Reconnaissance.*—The area over which the reconnaissance was made includes the northern part or nearly half of the Indian Territory, and a little of the adjoining part of Oklahoma. It includes the Cherokee, Creek and Seminole Nations, all the Indian Nations in the northeast corner of the Indian Territory, the northern part or nearly one-third of the Choctaw Nation and a little of Oklahoma adjoining the Creek and Cherokee Nations.

The area is about 165 miles long and about 125 miles wide and covers a little more than 20,000 square miles.

*Previous Investigators.*—In 1819, Thomas Nuttall[1] made several excursions across this region to study its botany and geology. He passed over the country southwest of Ft. Smith, Ark., between Sugar Loaf and Cavaniol mountains[2] and across Winding Stair mountains; then he went up the Arkansas river to Verdigris river and across the country in a southwesterly direction from Verdigris river. He also went up Grand river to the Salt springs and made short excursions in the vicinity of Salisaw and Lee's creeks. His conclusions regarding this field were: that sandstones, shales and coal-bearing rock extend over most of the area; that limestones and cherts all lie north of the Arkansas river; that the salt-bearing strata of Grand river are different from the salt-bearing red beds in the southwest, and that the mountain chains in central western Arkansas and central Indian Territory have a southwest trend.[3]

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[1] *A Journal of Travels into the Arkansa Territory*, by Thomas Nuttall, Philadelphia, 1821, pp. 146–177.

[2] *Cavaniol, Caveniol* and *Kavanaugh* are the different ways of spelling the name applied to the mountain lying between the Sugar Loaf and the Sans Bois mountains. *Cavaniol* is the oldest spelling of the name that has been found, and is the one used in this report.

[3] *Jour. Acad. Nat. Sci.*, Vol. ii, p. 49.

In 1822, Edwin James[1] published a geologic section and some explanatory notes of that part of this country lying along the 35th parallel of north latitude. This publication, however, gave very little additional information concerning the geology of this area since it only showed the Ozark mountain strata to be Carboniferous, and the rocks of the Canadian river country to be red beds bearing salt and gypsum.

In 1853, important geologic observations in this country were made by Jules Marcou,[2] geologist to the Pacific Railroad Expedition. His reconnaissance in this field was principally confined to the area lying immediately south of the Arkansas and Canadian rivers. The important additional geologic knowledge he gave of the area was: a better knowledge of the coals, the lithology, and the structure along the line of reconnaissance. He considered the Ozark mountain area an outlying or second fold of the Allegheny mountains.[3]

George G. Shumard made the statement before the St. Louis Academy of Science, in 1857, that he had traced the coal fields from Ft. Smith, Ark., to Ft. Belknap, in Texas.[4] He apparently did not note the break in outcrop of these beds in the southwestern part of the Choctaw Nation, where the Carboniferous is concealed by the overlying Cretaceous.

In 1890, H. M. Chance[5] published "The Geology of the Choctaw Coal Fields," which is the most valuable information yet published on the geology of this area. In this paper he locates the relative stratigraphic position in the Indian Territory of the three productive coal beds, and clearly outlines by description, sections, and maps, most of the Grady and McAlester coal beds along the outcrop from six or seven miles west of McAlester to near the Poteau mountains. He gives a section from the base of the Grady coal bed to the top of Cavaniol mountain, which includes the productive part of the Coal Measures. He also notes the prevailing S. 80° W. axes of folds and the system of southwest folds.

In 1891, R. T. Hill[6] published a paper outlining the Ouachita

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[1] *Jour. Acad. Nat. Sci.*, Vol. ii, pp. 326–329.

[2] *Pacific Railroad Reports*, Vol. iii, Part iv. pp. 123–127.

[3] "Esquisse d'une classification des chaines de montagnes d'une partie de l'Amérique du Nord," *Annales des Mines*, 5 me. sér., Tome vii, pp. 339, 340.

[4] *Trans. Acad. Sci.*, St. Louis, Vol. i, p. 93.

[5] *Trans. Amer. Inst. Min. Eng.*, 1890, Vol. xviii, 653–661.

[6] *Amer. Jour. Sci.*, Vol. xlii, August, 1891, pp. 111–121.

Mountain System in the Indian Territory, which further classified the knowledge of this system.

The work of the Arkansas and the Texas geological surveys, the geologic investigations in southeastern Kansas by Prof. Charles S. Prosser, and an unpublished sketch map kindly furnished by Prof. Orestes St. John, showing the general distribution of the geologic formations in the Indian Territory, further assisted in giving an idea of the geology of this area. Taken as a whole, however, the field was comparatively a new one to geologists and it is rather remarkable that it should have so long remained so little known.

*Hydrography.*—Nearly all of the area under consideration is drained by the Arkansas river and its tributaries. A very little of the southern part, however, is drained by streams tributary to the Red river. The Arkansas river enters the country under discussion a little south of the northwest corner, and runs in a southeasterly direction, thus crossing it diagonally through the central portion. To the north of this river the larger streams, the Illinois, the Grand, the Verdigris, and the Little Verdigris or Caney rivers, flow nearly southward and empty into the Arkansas river. The Illinois river, however, is somewhat deflected to the westward, and the Verdigris and Caney rivers deflected to the eastward. The streams on the north thus have a tendency to flow into the Arkansas river at the same locality.

To the south of the Arkansas river the Cimarron and the Canadian rivers are its largest tributaries. The Cimarron, the most northerly of the two, flows eastward into the Arkansas river, while the Canadian river is slightly deflected to the north in its eastward course, and enters the Arkansas river about twenty miles below the collecting basin of the streams to the north. Between the Cimarron and Canadian rivers, the Deep Fork and North Fork of Canadian rivers, flow almost eastward and unite a short distance above their confluence with the Canadian.

*Topography.*—There are three general topographic groups in this area. One is the elevated and folded area to the south, which is an extension of the Ouachita mountain system; a second group is the elevated plateau area in the northeast, which widens slightly southward to near the Arkansas and the Grand rivers. This belongs to the Ozark plateau system. The third group is a broad plain-like area that slopes gently eastward in terrace-like escarpments and undulations, and narrows into the low depression between the Ozark

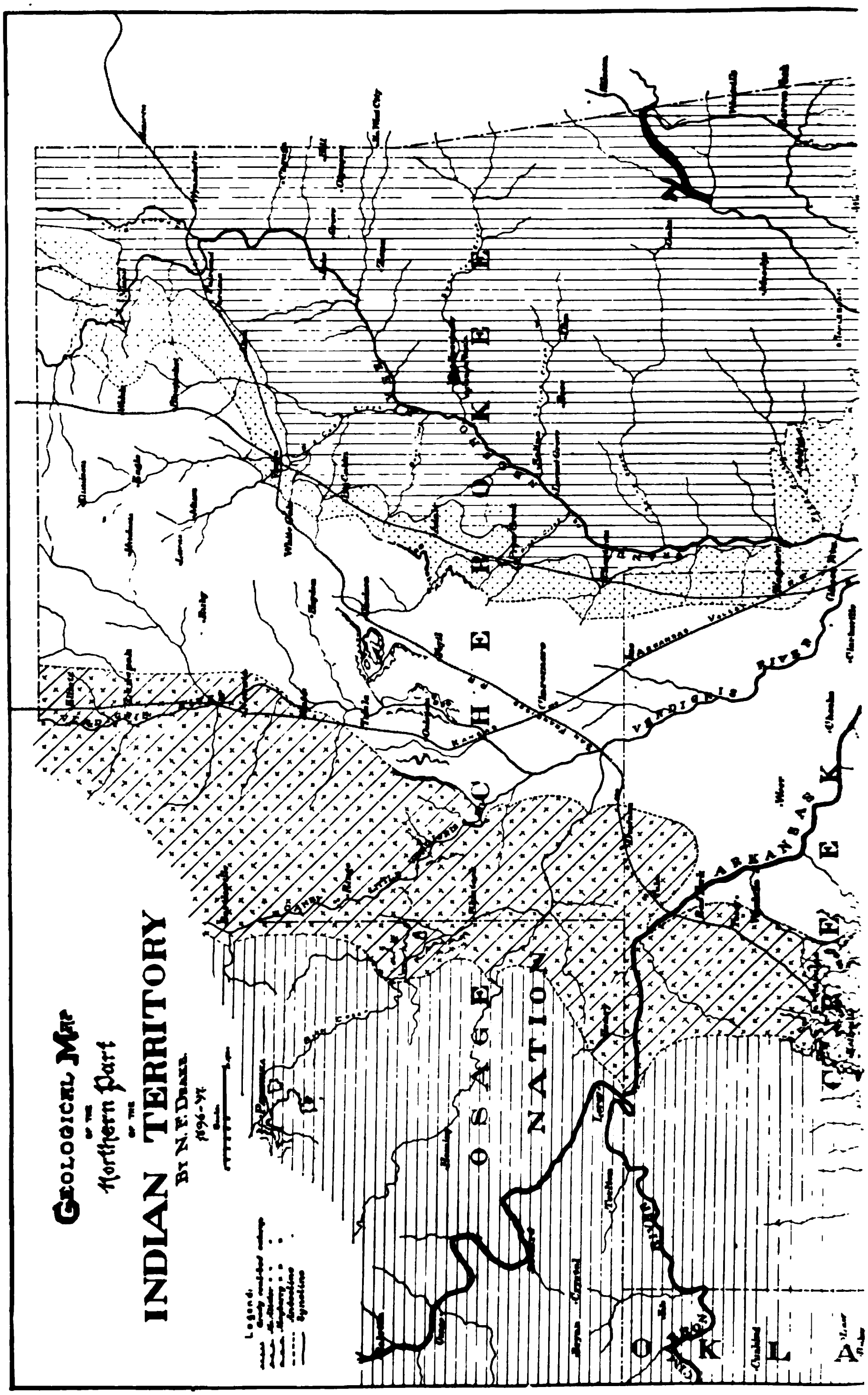
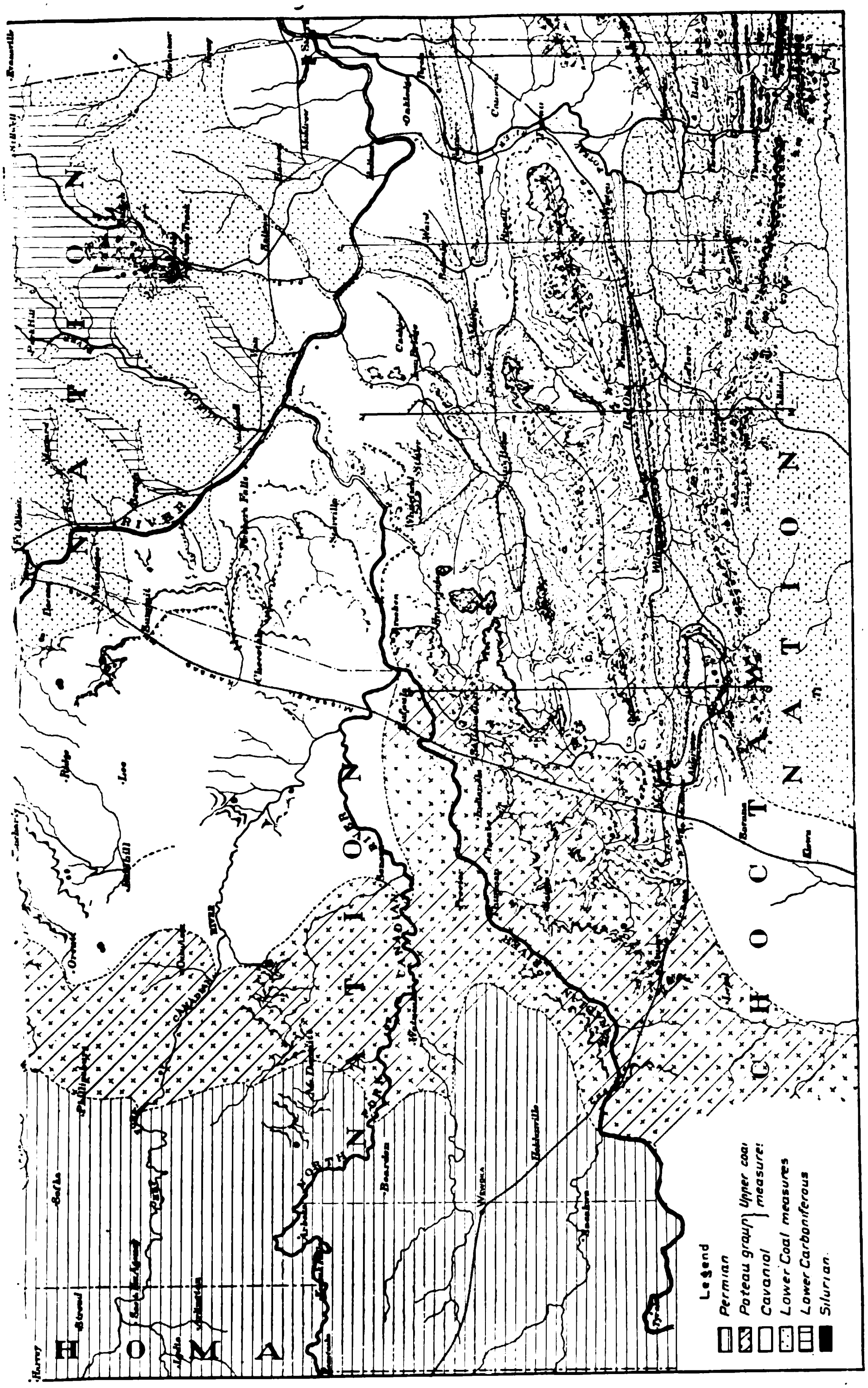

Geological Map
of the
Northern Part
of the
INDIAN TERRITORY
By N. F. Drake
1896-97.
Scale
Legend
CHEROKEE
OSAGE NATION
CREEK
OKLA
VERDIGRIS RIVER
ARKANSAS
Wagoner
Claremore
Clarksville
Weer

Plate 1.


Legend
Permian
Poteau group
Upper coal measures
Cavaniol
Lower Coal measures
Lower Carboniferous
Silurian.
CHOCTAW NATION

and the Ouachita mountain systems. The westward deflection of the Illinois and Grand rivers is due to the Ozark uplift, while the northern deflection of the Canadian river is caused by the uplifted folds of the Ouachita mountain system. Thus the rivers approach each other on either side of the Arkansas river along the border lines of these topographic groups.

*The Ozark Mountain System.*—This term was formerly applied to the mountainous area of southern Missouri, northwestern and central western Arkansas and east central Indian Territory. The name is, however, properly restricted to the plateau or northern part of this area, and the name, Ouachita, has been applied to the folded mountains of the southern part of the area.

The Ozark mountains in the Indian Territory are divided into two distinct topographic areas. One lying east of Grand river and north of Tahlequah and Evansville is the lower table-land of the two, and contains flat lands and also areas of sharp narrow ridges and small V-shaped canyons. The other portion of the Ozark system is more elevated and is the western prolongation of the Boston mountains. This area is triangular in shape; the apex of the triangle is about four miles southeast of Fort Gibson, the base lies south of Evansville, and is about fifteen miles across, measured along the Arkansas-Indian Territory line. This table-land is about 1500 feet above tide-level. It is usually bounded by steep escarpments on the north side and by both escarpments and slopes on the south. Several streams have cut through this plateau and at present flow through narrow valleys or canyons. The escarpment on the north side of the Boston mountains has a general east-west direction, but it is a very irregular line with plateau tongues and outliers extending northward along the face of the mountain; these are erosion remnants showing the former extension of the lower carboniferous strata.

*The Ouachita Mountain System.*—The elevated topographic group in the southern part of the field is an extension of the Ouachita mountain system which forms such a typical area of folded strata and parallel ridges and valleys in western Arkansas. This system was named[1] by Dr. J. C. Branner, who thinks it is an outlier of the Appalachian system and the structural equivalent of the Cincinnati-Nashville anticline. The Appalachian system, he thinks, once extended across the Mississippi Valley south of the Ouachita mountains, through Mississippi, Louisiana and central Texas.[1] There are two principal types of mountains in the Ouachita system; one of these consists of long ridges, the other is the bench-and-bluff and flat-topped mountain type. The mountains, ridges and valleys of this region trend almost east and west, corresponding to the folds.

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[1] *Ann. Rept. Geol. Surv. Ark.*, Vol. ii, 1888, p. 175.

The Canadian river and the Arkansas river from the mouth of the Canadian river to Arkansas, practically form the northern boundary of this group. For some fifteen to twenty miles south of these rivers low isolated buttes, table-lands and ridges such as Long mountain, the Seven Devils, McChar mountains and Backbone mountain are the outliers to the typical part of the mountain system. Immediately south of these outliers are the Sugar Loaf, the Cavaniol and the Sans Bois mountains, each rising nearly 3000 feet above tide-level. They all trend about S. 80° W., but are completely separated.

These three mountains, together with the Poteau mountains, and many smaller elevations, are of the bench-and-bluff type. The mountains farther to the south, the Walker, the Blue, the Winding Stair, the Black Fork and the Rich mountains are of the ridge type.

*Prairie Plains.*[2]—The third topographic division comprises all the country north of the Canadian river and west of Grand river. The predominant topographic feature of this division is a broad southeastward sloping plain, broken by gentle irregular undulations and by long lines of escarpments facing east or east-southeast. Of these features the east-facing escarpments are the most conspicuous. They are usually but fifty to one hundred feet high, although often from ten to fifteen miles long, and even much longer if local breaks are not taken into account. Occasionally gentle westward slopes extend from the top of one escarpment back to the base of the one next west of it, but usually the inclination is not sufficient to bring the base of the western escarpment down to the level of the eastern one.

*Structure of the Topographic Groups.*—In each of these topographic groups the geologic structure accounts for the topographic forms. The plateau type in the northeast has its strata almost horizontal; the folded type in the southern part of the field has its strata irregularly folded along nearly parallel lines; in the western part of the field the escarpments and undulating topographic features are due to the varying resistant power of gently westward dipping beds.

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[1] *Proc. Bost. Soc. Nat. Hist.*, Vol. xxvi, p. 477; *Am. Jour. Sci.*, November, 1897, pp. 357–371.

[2] J. W. Powell, *National Geogr. Monographs*, Vol. I, No. 3, p. 83.

*Ouachita Mountain Structure.*—In the central and northern part of the Ouachita area the mountains and mesas are practically all synclinal in structure, and the deeper and broader synclines form the larger mountains, such as Sugar Loaf, Poteau, Cavaniol and San Bois mountains; the mesas, such as the Seven Devils and McChar mountains, occupy the smaller synclinal folds. In the southeastern part of the field all the mountains and ridges are upturned edges of extensive hard rock beds. There is every gradation from the sharp ridge with equal slopes on either side and its steeply dipping strata, to the escarpment or bench topography with its gently dipping beds.

*Ouachita Valley Structure.*—In the central and northern part of the Ouachita area most of the larger valleys lie along anticlinal axes, while in the southeastern part of the field the valleys are in the softer strata or along faults, and are nearly always parallel to the structural lines.

*Folds and Faults.*—The folds and faults belong principally to that part of the field included in the Ouachita mountain system. The limits of the folded area are not sharply marked, however, and there are isolated folds and faults through and around the Ozark mountains. There are two distinct systems of folds, a primary system and a secondary one. The axes of the most characteristic or primary system run about S. 80° W. The axes of the secondary system run approximately northeast–southwest, but the different folds of this system vary much in direction on either side of the general direction. It does not appear that these two systems of folds are of different ages, because the topographic features have developed equally along corresponding kinds of folds regardless of the direction of their axes, and also because the two systems are intimately related, as is shown by certain folds lying in both systems. As already stated, the axes of the principal folds run nearly east and west and the folds are quite regular. The distinctness of the secondary folding is shown by the general southwest direction of many axes and by the west-northwest dip of all the rock beds in the central and western part of the whole area of the reconnaissance. These western beds dip nearly northwest in the southern part of the area, to the west-northwest in the central, and to the west in the northern part of the Indian Territory. Thus the strike swings around so as to become parallel to the western end of the Ozark mountain uplift. This secondary system of folds is more characteristic of the northern part of the region, thus further showing its intimate connection with the Ozark mountains. So it appears that the force that threw the Ouachita mountain system into east and west folds at the same time uplifted the Ozark mountains to the north and started secondary north-south folds.

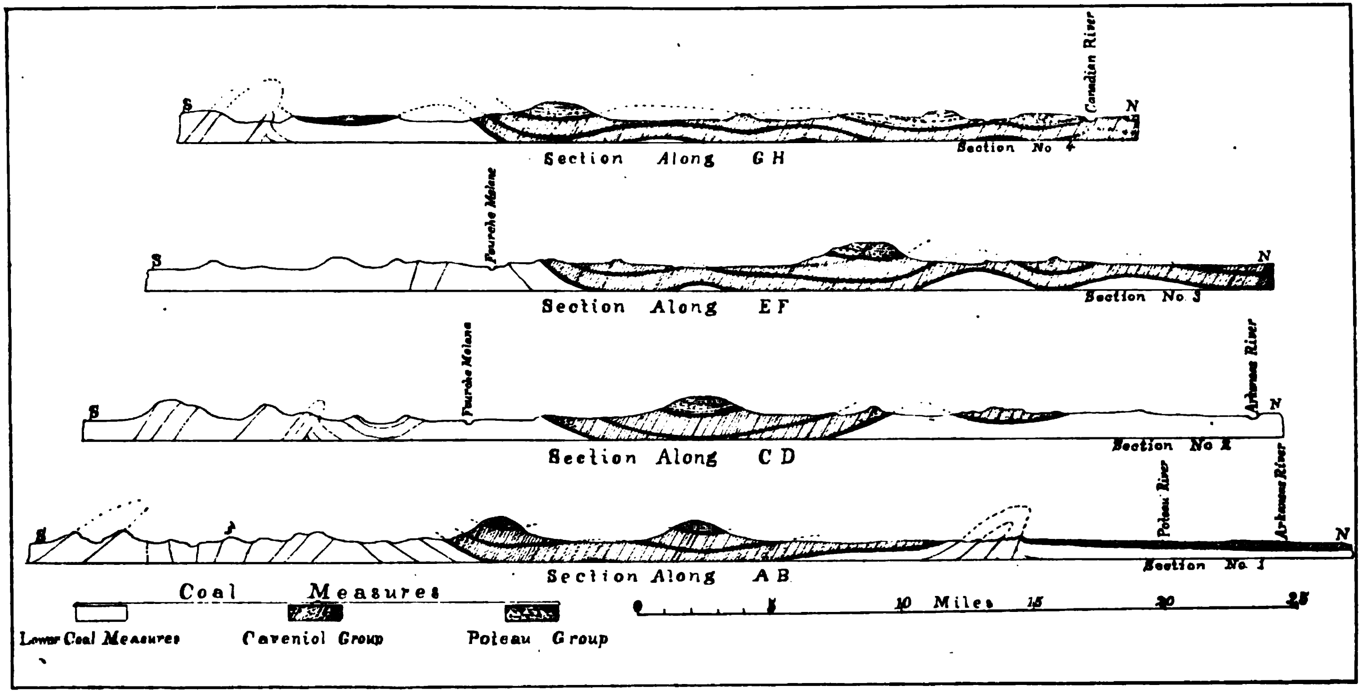
The sketch map of the Choctaw coal field shows that there are three groups of the south 80° west folds that are especially prominent. The group on the north is anticlinal and runs westward from immediately south of Pocola, passing near Farmer and Milton, and running through Sans Bois to the west end of Sans Bois prairie. This group includes three separate anticlinal folds, or the Backbone, the Bokoshe-Milton and the Sans Bois anticlines.

The group lying immediately south of this is composed of three separate synclines, the Sugar Loaf, the Cavaniol and the Sans Bois synclines, giving axial direction to the mountains of those names. The third group, farther to the south, is anticlinal and extends from immediately north of Heavener westward, with some minor deflections, passing near Krebs and through McAlester. This is a continuous anticlinal fold. To the north of these three groups the folds are more gentle and irregular, while to the south of them the folding is also more irregular and decidedly more violent and accompanied by faulting. So in the southern part of the field the structure can only be worked out by detailed study.

Folds of the second system, or those running nearly northeast-southwest, are all gentle and not so extensive. The most prominent folds of this system are those separating the Sugar Loaf, Cavaniol and Sans Bois mountains, and those lying between Ward and Whitefield. Of all these the one separating Cavaniol and Sans Bois mountains is the most prominent, and it is only a gentle roll.

*Characteristics and Origin of the Folds and Faults.*—The intensity of folding and faulting increases quite regularly southward, as is shown in Secs. 1, 2, 3 and 4, Pl. II, and this intensity of folding extends further westward in the southern part of the area. Along any given east and west line the folding is usually more intense to the east; this, however, is due chiefly to the southward deflection of the west end of the principal folds. As a rule, the strata on the north side of anticlinal folds dip more steeply than on the

*Plate II.*

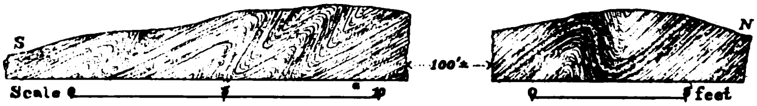


Sections across the Choctaw coal field.

south side of the same folds, as is shown in Secs. 1, 2, 3, 4, 5, 6, 8, and A. This feature is more marked where the folding is intensified. Where the anticlines are very closely pressed, overthrows to the north and often faulting along the north side of the anticlines are the usual consequences; this is shown in Secs. 5, 6 and Pls. II and VII. In the Ozark mountain area the faults are usually normal, while in the Ouachita area the faults are along anticlines.

All mountains of importance in the southern part of the field (Walker, Black Fork, Rich, Blue, Winding Stair, Jack Fork and Kiamichi mountains) have practically all their beds dipping south about 40°. Throughout the area including these mountains, the folds are so closely pressed, overthrown, and faulted that the strata no longer show broad anticlines with low dips.

The elevation of the region, the increased intensity of folding toward the south, and the overthrows toward the north all show an upward and northward movement of the rock beds at the time of folding. In places these movements of the strata have produced wrinkles like that shown in Sec. A.



Sec. A. To illustrate Ouachita folded structure. Sketched from exposures along a railway cut, five miles southeast of Bengal.

This movement has tilted beds 40° to the south, the angle at which they best resisted breaking and crushing. As noted by Marcou,[1] Branner[2] and Griswold[3], these disturbances are probably contemporaneous with the Allegheny mountain uplift, and as noted by Winslow[4] they are probably due to the raising of the isogeotherms in the great thickness of Paleozoic beds.

*Lithology of the Area of the Reconnaissance.*—This field includes both igneous and clastic rocks. The igneous rocks, however, are confined to one small granitic dike in the Cherokee Nation. Among the clastics, shales, sandstones, limestones and cherts have extensive developments.

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[1] *Annales des Mines*, 5me sér., vii, pp. 339, 340.

[2] *Ann. Rep. Geol. Sur. Ark.*, 1890, iii, p. 213.

[3] *Proc. Bost. Soc. Nat. Hist.*, xxvi, pp. 474–479.

[4] *Bull. Geol. Soc. Am.*, 1891, ii, pp. 231–234.

## IGNEOUS ROCKS.

*Previous Knowledge of the Igneous Rock.*—The existence of igneous rock in the Cherokee Nation has been known for a long time. It was referred to in D. D. Owen's *Second Report of the Geology of Arkansas* as a red granite which occurred at the mouth of Spavinaw creek, some thirty or forty miles west of the Arkansas line. Edward T. Cox failed to find the granite in place, but saw some millstones that were made from it, and obtained specimens which were broken off in fashioning the millstones. He thought this granite underlay the sedimentary rocks of southwestern Missouri and northwestern Arkansas.[2]

The exact locality of this granite outcrop has, however, apparently never been definitely known to any one interested in the geology of the country until 1896, when the writer, after a special search, found the rock in place.

*Locality and Mode of Occurrence.*—The rock occurs in the Cherokee Nation, on the north side of Spavinaw creek, about six miles from its mouth and three-fourths of a mile west of Spavinaw postoffice. It is a dike about twelve hundred feet long by fifty feet wide. The outcrop is not continuously exposed, but the breaks are probably due to a thin covering of detritus from the clastic rock. There are four exposures of the dike rock, which vary in length from about one hundred to two hundred feet, and occur at intervals of about two hundred feet.

This dike runs along the axis of a gentle anticlinal fold which extends about N. 30° E. The dips of the sedimentary beds on either side of the dike are only 5° to 10°, but the fold is broad and affects the rocks for two to three miles to the west and probably as far to the east. Silurian strata which, over the adjoining country, are usually covered by two hundred to five hundred feet of Lower Carboniferous beds, are here exposed to a depth of about two hundred feet and outcrop in the valley, as shown in Pl. III. The Silurian strata along the contact of the dike appear to be free from any special metamorphic action due to the dike rock.

*Macroscopic Characters.*—The general color of the rock is a light brick red with a mingling of black specks which are slightly grouped and in places so much as to give it a somewhat

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[1] *Second Report of a Geological Reconnaissance of the Middle and Southern Counties of Arkansas, 1859 and 1860*, pp. 404, 408.

[2] *Ibid.*, p. 408.

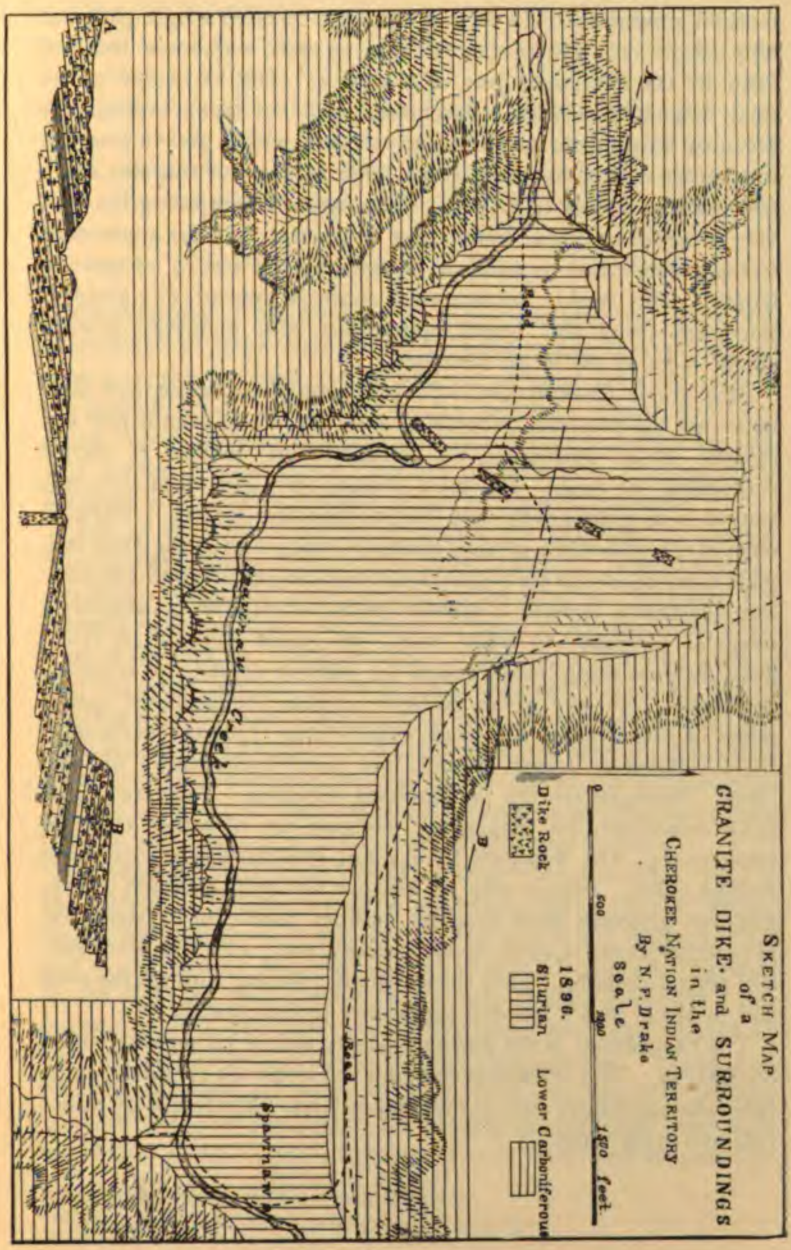
SKETCH MAP
of a
GRANITE DIKE. and SURROUNDINGS
in the
CHEROKEE NATION INDIAN TERRITORY
By N. F. Drake
Scale
0
500
1000
1500 feet
1896.
Dike Rock
Silurian
Lower Carboniferous
Spavinaw Creek
Road
Road
A
A
B
B

Plate III.

mottled appearance. In the red color are blended a light pink and also deeper red, due to the feldspar crystals, which are red and form by far the larger part of the rock. The black specks are small magnetite crystals. Associated with the black crystals are greenish hornblende and chlorite crystals, which give a greenish tint hardly noticeable on a casual observation. It contains also a few small white quartz crystals. The crystals composing the rock vary in size from those which give a general granular appearance to the ground mass to feldspar crystals that are 1 c. m. or more in length. The freshly broken rock shows a general fine-grained, somewhat shiny and bright appearance with numerous shining crystal faces of the larger feldspars.

*Microscopic Examination.*—Feldspars, quartz, chlorite and magnetite are the principal minerals of the rock, while hornblende and epidote occur sparingly. A holocrystalline texture is shown throughout the rock. The most striking and general microscopic feature is its granophyric and micropegmatitic texture. Through most of the orthoclase crystals quartz is intergrown in the most intimate manner, so that each feldspar shows radiating or parallel alternating quartz and feldspar in narrow bands, which form fan-shaped or irregular patches. In other cases, the quartz appears in triangular sections along lines through the feldspar crystals, or is micropegmatitic. In any given feldspar crystal, the included quartz plates or prisms show the same orientation. Quartz occurs sparingly isolated in larger crystals, but very rarely shows its outlines. Feldspars are the predominant minerals. They are principally orthoclase, but plagioclase feldspars are of rather common occurrence. The feldspars have a fine granular appearance and a reddish color. Phenocrysts of feldspar are quite common; they, however, generally show irregular outlines instead of crystal faces. Magnetite occurs in small opaque masses, many of which show perfect crystal outlines. They show a slight grouping through the rock and in places give a blended appearance to the crystals.

The hornblende is the greenish variety and of rather uncommon occurrence. The chlorite is common and occurs in greenish bands, spherular aggregates and in minute particles. Epidote is of rather common occurrence.

*Chemical Analysis.*[1]—

| | PER CENT. |
|---|---|
| Loss on Ignition | 1.11 |
| Silica ($SiO_2$) | 71.10 |
| Ferric Oxide and Alumina ($Fe_2O_3$ and $Al_2O_3$) | 20.60 |
| Calcium Oxide ($CaO$) | 2.53 |
| Magnesium Oxide ($MgO$) | 0.99 |
| Potassium and Sodium Oxide ($K_2O$ and $Na_2O$) | 3.76 |
| Total | 100.09 |

*Classification of the Rock.*—The high percentage of silica, the holocrystalline texture and the general interference of crystallization shown in the irregular crystal outlines at once place the rock in the granitic series. As shown by the feldspars, quartz and magnetite, however, there is a strong tendency to the porphyritic texture: it is, therefore, a porphyritic granite. The minute textures of the feldspars and quartz is designated by the name granophyre.

*Age of the Dike.*—As noted above, the dike breaks through Silurian strata along the axis of an anticlinal fold. The Lower Carboniferous strata overlying the Silurian are tilted by this fold. The igneous rock was, from this evidence, most likely protruded at the time of the folding. This anticline is one of the outlying folds of that mountain system which is such a marked feature of central western Arkansas and the adjoining part of the Indian Territory. This system of folding is post-Carboniferous, pre-Cretaceous and quite likely pre-Mesozoic, because Upper Coal Measures deposits are folded, Lower Cretaceous deposits lie almost undisturbed upon these folds and no Jurassic or Triassic beds occur over the area.

*Relation to the Igneous Rocks of Other Areas.*—This dike in the Cherokee Nation is equally distant from three different igneous rock areas, and about two hundred miles from either of them. One lies in southeastern Missouri, one in central Arkansas and the other in the Choctaw and Chickasaw Nations, Indian Territory. The igneous rocks of this latter-named area have not been studied by any one sufficiently to make satisfactory comparisons. The igneous rocks of Arkansas are quite different from the Spavinaw granite. Those of Arkansas "belong to the eleolite syenites and their associated dike rocks;" they are gray or blue in color[2] and are post-Carboniferous in age. In texture, color and mineralogical composition many of the Missouri granites closely resemble those of the Spavinaw area. The resemblance is especially true of the granophyric and micropegmatitic texture. Dr. Haworth says:[1] "The distribution of rocks exhibiting such structure is very wide; there is scarcely a granite in the State in which portions of it are not represented. . . . . The small outlying granitic areas generally have this structure throughout. . . . . This structure is common in the porphyries also."[2]

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[1] Analysis made by Mr. Chester A. Thomas.

[2] *Ann. Rept. Geol. Surv. Ark.*, 1890, Vol. ii, p. 3.

Iron oxide is a rather common constituent of the Missouri granites, and is especially common in the porphyries.[3] These properties in general are also characteristic of the Spavinaw rock. The age of the Missouri granite, however, is apparently different since it has been referred to the Archean.[4]

## CLASTIC ROCKS.

The clastic rocks which cover all this area, except the small dike described, belong to the Silurian, the Lower Carboniferous, the Coal Measures and the Permian.

The Silurian occurs in a few narrow valleys in the northeastern part of the area. The Lower Carboniferous covers about half of the Cherokee Nation, or the northeastern part of the field under discussion. The Coal Measures cover all the rest of the area except a narrow strip along the western edge, which is Permian.

### SILURIAN.

The Silurian areas lie in narrow strips along valleys in the Cherokee Nation, where stream erosion has cut down through the overlying Lower Carboniferous beds. In some places folding has elevated these lower beds so that erosion has more readily exposed them.

*Structure.*—The Silurian strata lie almost horizontal and closely conform to the inclination of the overlying Lower Carboniferous beds.

*Lithology.*—The strata are composed of saccharoidal sandstones, marble or highly metamorphosed limestones, chert and dolomitic calcareous sandstones.

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[1] *Mo. Geol. Sur.*, Ann. Rept., 1894, Vol. viii, pp. 165-166.

[2] *Ibid.*, p. 193.

[3] *Ibid.*, pp. 141, 188.

[4] *Ibid.*, pp. 95-96.

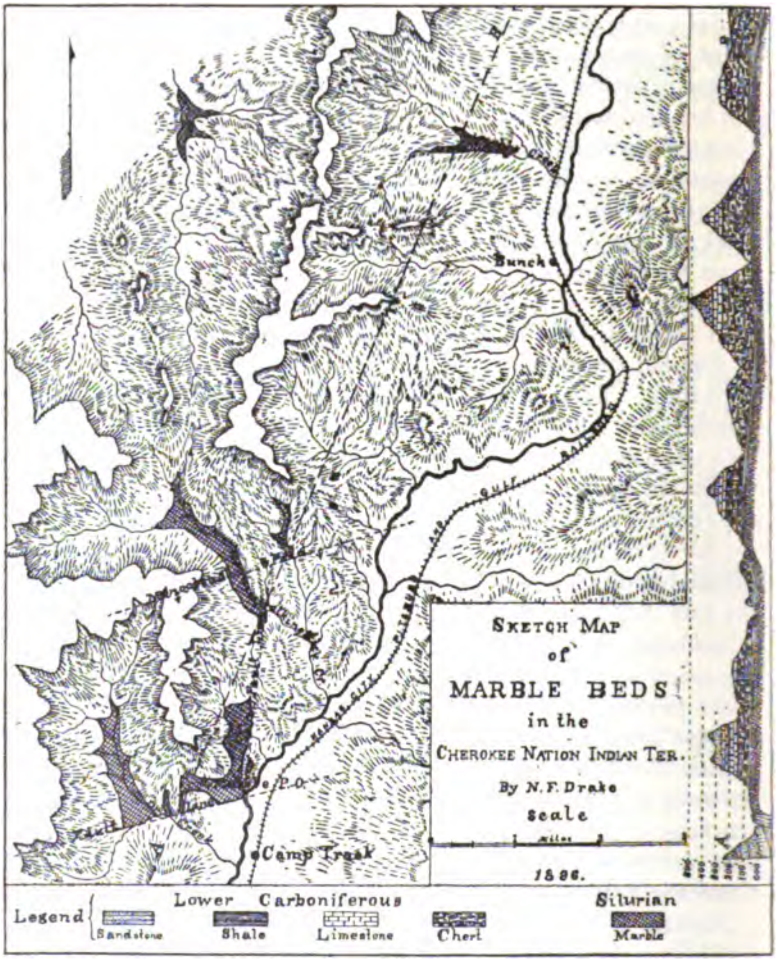
*Local Development.*—The localities where the writer saw and examined Silurian deposits are on Spavinaw creek six to seven miles from its mouth, along the Illinois river southeast of Oaks, along Salisaw creek at and near Marble and on Elk creek west of Bunch.

*Spavinaw Creek Area.*—The area on Spavinaw creek is shown in Pl. III. It is about one mile square, and is exposed mainly on account of an anticlinal fold which elevates the beds so that the erosion of Spavinaw creek has reached and cut into them. About two hundred feet of the strata are exposed. The rocks are mainly cherty limestones, cherty calcareous sandstones and saccharoidal sandstones. The lowest exposed strata lie practically in contact with the igneous dike and are composed of fossiliferous chert. Along the creek at Spavinaw post-office twenty feet or more of the Silurian strata are exposed.

*Illinois River Areas.*—At the Stewie ford of the Illinois river on the Cincinnati-Oaks road, about seventy-five to one hundred feet of Silurian strata are exposed in the bluffs and the hillsides along the valley. These strata are mainly saccharoidal sandstones, rather thin bedded, but sandy clay shale is quite frequently interstratified with the sandstone. These clays are of a light gray color and in places are slightly blue, and some are yellowish. Silurian strata are exposed on the above-named road also about two miles to the northwest of the ford, at which exposure the beds are saccharoidal sandstones dipping slightly to the southeast. Good exposures of the thin bedded sandstone and shales may be seen at the Stewie schoolhouse about one-half mile northwest of the ford. From the exposures seen along and near the river, it seems likely that the outcrops extend several miles up and down the valley from the ford. Silurian strata are reached by this river erosion along the Arkansas-Indian Territory line, and they are nearly reached in the bed of the river east of Greenleaf courthouse, some twelve to fifteen miles southeast of Tahlequah. So it is probable that exposures may be seen for twenty or thirty miles along the river valley within the Cherokee Nation.

*Salisaw Creek Areas.*—The exposures of Silurian deposits on Salisaw creek were caused by folding, faulting and erosion. The location and areal outcrop of these beds are shown in Pl. IV. The Silurian strata nowhere rise high upon the hillsides, but are almost entirely confined to the deeper erosion channels of the valleys and cañons. They are exposed, however, only where folding or faulting has brought them to a higher level than they would otherwise have reached. There are in this area two systems of folds and fault lines; one runs about 10° south of west, and the other 10° east

*Plate IV.*



of north. One of the S. 80° W. fault lines runs from a point about one-half mile southeast of Marble P. O. westward across Dry creek. From the first-named point, a fault line runs N. 10° E. across Walkingstick creek, where it meets a monoclinal fold running nearly east and west apparently. The uplift of the monoclinal fold being on the north side, outcrops of the Silurian strata extend farther east on that side of the fold. Another east and west anticlinal fold appears to lie about one mile north of Bunch. Silurian rocks are exposed along this uplift one and a half miles northwest of Bunch, and on Elk creek about six miles W. N. W. from Bunch.

*Lithology of the Salisaw Creek Area.*—Marble and saccharoidal sandstone are practically the only kinds of rocks exposed in these outcrops. There is, however, a bed of chert some twenty-five feet thick one-half mile west of Marble, which is most likely Silurian. This chert consists of angular pieces, from an eighth to a fourth inch in diameter, of pink and also white chert scattered through a ground mass of gray chert. At the base of the chert bed, there is some saccharoidal sandstone containing chert nodules. The saccharoidal sandstone usually lies at the top of the Silurian beds in this area, and is from one inch to twenty-five or thirty feet thick. The grains composing the sandstone vary considerably in size: the largest are about two millimeters in diameter. These sandstones may be seen along Walkingstick creek above the Marble bed, at almost every place where the top of the marble is exposed. They also outcrop one-half mile east of Marble on Salisaw creek, and northwest of Marble along Dry creek. The marbles are generally of a pink color, rather coarsely crystalline, seamed, and lie in massive beds; twenty-five to thirty feet of massive marble is exposed at all the larger Silurian areas marked on Pl. IV, and the base of the marble was not seen at any place. Mr. J. D. Rice, who quarries marble at Marble P. O., gave me the following section from a drill hole on Dry creek, northwest of Marble P. O.

| | FEET. |
|---|---|
| Pink marble | 25 |
| Light gray marble | 100 |
| Deep pink marble | 2½ |
| Dark gray marble | 2½ |
| Deep pink marble | 5 |
| Dark gray marble | 1 |

*Relation to the Silurian of Arkansas.*—A section[1] of the Silurian deposits in Arkansas gives something over one hundred and fifty feet of pink, chocolate and gray-colored marbles on top, which beds are called St. Clair marbles. These beds are underlain by blue and gray limestones called the Izard limestone. The Izard limestone is underlain by saccharoidal sandstones, magnesian limestones and cherts.

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[1] *Ann. Rept. Geol. Sur. Ark.*, 1890, Vol. iv, pp. 10, 11, 214.

All the Silurian deposits seen in the Indian Territory, except the Salisaw and Elk creek areas, are composed of saccharoidal sandstones, cherts and calcareous, magnesian sandstones. The Salisaw and Elk creek Silurian rocks, however, are mainly pink and gray marbles, and therefore appear to be the equivalent of the St. Clair marble, while the Illinois river and Spavinaw creek areas belong to the beds below the Izard limestone.

The St. Clair marbles in Arkansas are principally confined to Independence, Izard, Stone and Searcy counties, in the northern part of the State. The Izard limestones have a somewhat wider range,[1] but neither the St. Clair marble nor the Izard limestones are known as far northwest as Benton county, Ark.,[2] or to the west of Benton county, in the Indian Territory. So it appears that these topmost Silurian beds were eroded in the northwest to a greater extent than they were to the south and east, before they were covered by later deposits. Dr. Henry S. Williams,[3] principally from biological investigations, has determined the top of the St. Clair marble to be of Clinton-Niagara age, and the lower part of it to be of Trenton age. From the thickness of the marble beds in the Salisaw creek areas, as shown by drill holes, it is probable that the outcropping part is the equivalent of the Clinton-Niagara part of the St. Clair.

## LOWER CARBONIFEROUS.

*Area.*—The Lower Carboniferous is confined to the northeast part of the Cherokee Nation and is roughly bounded on the west by the Grand or Neosho river and on the south by the Boston mountains. This area covers about three thousand square miles, approximately one-half of the Cherokee Nation.

*Lithology.*—The rocks composing the Lower Carboniferous are cherts, limestones, shales and sandstones.

*Structure.*—The beds as a rule are practically horizontal, especially in the northeastern part of the area. Along the western border of the area the strata dip slightly to the west, while along the southern border they are somewhat disturbed by gentle folds which usually run a little south of west by north of east; but many run about northeast by southwest. The general result of the disturbance is to make the strata dip with varying steepness to the south.

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[1] *Ann. Rept. Geol. Sur. Ark.*, 1890, Vol. iv, p. 112.

[2] *Ann. Rept. Geol. Sur. Ark.*, 1891, Vol. ii, pp. 27–32.

[3] *Am. Jour. Sci.*, 1894, Vol. cxlviii pp. 328, 329.

## EUREKA SHALE.

This shale is black, argillaceous, bituminous and rather friable and varies in thickness from one inch to forty or fifty feet. It immediately overlies the Silurian beds and is apparently unconformable with them since the shale lies on cherts and saccharoidal sandstones along Spavinaw creek and Illinois river, while about twenty-five miles farther south it lies on higher strata composed of one hundred and fifty feet or more of Silurian marble. Similarly, in Arkansas, the shale lies on top of the St. Clair marble and the Izard limestone along the southern border of the Silurian area, while farther to the north it rests on cherts and saccharoidal sandstones which underlie the marbles and limestones.

The shale is apparently conformable with the overlying beds, since the limestone at the base of the Boone chert was found resting on it at every place where it was seen. The shale may be seen at nearly every locality where Silurian beds are exposed, and at a few places where the erosion has not passed through the shale bed. Quite often detritus from overlying rock beds covers and obscures the outcrop of the shale, but by tracing the horizon a short distance it is usually found.

The Eureka shale has a wide distribution outside of the Indian Territory. It is usually found in northwestern Arkansas wherever the base of the Boone limestone is exposed. From its typical development at Eureka springs, Ark., it was named by Dr. J. C. Branner, the Eureka shale.[1]

Dr. Branner says: "The Eureka shale is clearly the equivalent of the Tennessee bed called by Safford the 'Black shale.'"[2] Safford says this shale also occurs in Virginia, Georgia and Alabama.[3]

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[1] *Ann. Rept. Geol. Sur. Ark.*, Vol. iv, 1890, p. 345; "Phosphate Deposits of Ark.," *Tran. Am. Inst. Min. Eng.*, 1896, xxxvi, 580–582.

[2] *Ann. Rept. Geol. Sur. Ark.*, Vol. iv, 1888, p. 26; "The Phosphate Deposits of Arkansas," *Trans. Am. Inst. Min. Eng.*, 1896, xxxvi, 582.

[3] *Elementary Geol. of Tenn.*, by James M. Safford and J. B. Killebrew, Nashville, 1885, p. 75.

The "Black shale" of Tennessee was referred to the Devonian[1] by Safford. The Eureka shale of Arkansas was referred doubtfully to the Devonian.[2] Dr. Branner thinks the shale belongs to the Lower Carboniferous,[3] because in places it grades into the overlying Lower Carboniferous limestones, and the few fossils that have been found in the shale belong equally to the Devonian and the Lower Carboniferous. The persistency with which such a thin bed occurs unconformably with the Silurian and conformably with Lower Carboniferous beds in the Territory, as well as in Arkansas, also strengthens the theory that it is Lower Carboniferous.

*Spavinaw Creek Area.*—Exposures of the shale are common around the border of the Silurian area on Spavinaw creek. One of the best exposures seen there was about one mile west of Spavinaw post-office, on the north side of Spavinaw creek. At that point it is about forty feet thick, and is the usual typical, bituminous, rather friable shale.

*Illinois River Areas.*—On the north side of the Illinois river, west of the Cincinnati-Siloam Springs road, and near the Arkansas-Indian Territory line, good exposures of the shale may be seen. Near the Stewie ford of the Illinois river, along the Cincinnati-Oaks road, the shale outcrops again. In the limited area examined, no complete section was seen, but it appeared to have its usual thickness and characteristics. West of Bunch, at a point about four miles below the mouth of Elk creek, the Eureka shale outcrops in the bed of the Illinois river.

*Salisaw Creek Areas.*—About two miles northwest of Bunch, along Marble creek, the valley shows the typical Eureka shale soil, but no good exposures of the shale were seen there. Along Walkingstick creek, however, about three and a half miles north of Marble, good exposures of the shale may be seen. At this locality it is about thirty feet thick and contains some calcareous nodules, otherwise it does not vary from its general characteristics. Along Dry creek, one and a half miles northwest of Marble, good exposures of the shale show it to be about thirty feet thick.

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[1] *Elementary Geol. of Tenn.*, by James M. Safford and J. B. Killebrew, Nashville, 1885, pp. 112, 118.

[2] *Ann. Rept. Geol. Sur. Ark.*, 1891, Vol. ii, p. 32.

[3] "Phosphate Deposits of Arkansas," *Trans. Am. Inst. Min. Eng.*, *loc. cit.*

## BOONE CHERT AND LIMESTONE.

*Stratigraphic Position.*—Immediately above the Eureka shale, there is a series of cherts and limestones aggregating from fifty to about five hundred feet in thickness, and averaging about three hundred and fifty feet. It was named the Boone chert by Dr. Branner because of its extensive and typical development in Boone county, Ark.[1] These beds are the probable equivalents of the Burlington-Keokuk divisions of the Lower Carboniferous.

*Areal Extent.*—The Boone chert and limestones form the principal strata outcropping over several counties in southwest Missouri and northwest Arkansas, and continue into the Territory, where they cover half of the Cherokee Nation—three thousand square miles. They lie in the northeastern and east central part of the Cherokee Nation. Roughly, their western limit is four to five miles west of Grand river and their southern limit some twenty to twenty-five miles north of the Arkansas river. Tracing the boundary more definitely, it enters the Territory south of Baxter Springs, Kans., curves to the southwest, passing through Miami, thence bears southward to near Fairland, whence it extends southwestward to a point on the M. K. & T. Railway, some four or five miles southwest of Vinita. From this point it runs southward in a wavy line between the railway and Grand river to a point about fourteen miles north of Ft. Gibson. From this point it runs eastward in a zigzag way to a point about one and a half miles south of Tahlequah. Then in its eastward course it swings southward, passing a little south of Park Hill, makes deep southward swings on the Illinois river, Salisaw and Lee's creeks, and passes into Arkansas a little north of Evansville. All along this border, and more especially its southern part, there are small isolated areas of higher geologic horizons scattered over the chert area along drainage divides.

*Structure.*—Over most of this area the beds are practically horizontal, but nearer the borders the strata dip toward and at right angles to the border line. In the northwest part of the area this dip, even along the border line, is barely perceptible, but toward the south the dip increases and also becomes more irregular by the increased folding and some faulting along several axes. These disturbances largely account for the irregular border of the chert area on the southwest and south.

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[1] *An. Rep. Geol. Sur. Ark.*, 1890, Vol. i, p. 129.

*Stratigraphy.*—Most of the formation is chert, and the limestone strata are usually confined to the base and top of it. These two limestone horizons are usually five to twenty feet thick each. The limestone interstratified with the chert is in thin layers, seldom more than two or three feet in thickness, and is of rather rare occurrence.

*Characteristics of the Chert.*—The chert varies in color from white to gray; light gray or white is the prevailing color, and is especially characteristic of the rock that has been exposed to weathering agencies, or is dry. Weathered pieces, however, are often of a brownish color. The rock is almost a uniform mixture of lime and silica, but the proportion of lime and silica varies somewhat at different horizons or even along the same stratum. In weathering it breaks into rather small sharp angular pieces. The strata are usually thin and present a slight wavy and much fractured appearance. These features are doubtless due to the weathering of rock of an uneven composition. These irregularities and characteristics run through the whole chert bed throughout the entire area.

*Limestones.*—The limestone at the base of the chert bed corresponds to the St. Joe marble of the Geological Survey of Arkansas;[1] it varies from an inch to about thirty feet in thickness; it is of rather uniform texture, quite crystalline, of a rather dark-gray color, and lies in strata from a few inches to four or five feet in thickness. This bed is rarely missing where the base of the Boone chert was seen. On Spavinaw creek and Illinois river it is from fifteen to twenty feet thick. On Dry creek, one and a half miles northwest of Marble, it is about two feet thick, crystalline, gray in color, and contains greenish specks scattered through it.

The limestone that occurs very sparingly through the chert is rarely more than two or three feet thick. It is usually of uniform texture, tough, and of a gray color.

The limestone at the top of the chert is from fifteen to forty feet in thickness. It is massive, tough, gray and crystalline, but in the northwestern part of the area it is arenaceous and somewhat flaggy. This limestone forms the base of a great many small hills along the border of the chert area. It is often marked by glades due to thin soil. Along the west bank of Spring creek, near the south line of the Quapaw Nation, hard gray massive beds of the upper Boone limestone are finely exposed in bluffs and benches known as the Devil's Promenade. Along the east bank of the Neosho river, south and southwest of Miami, the upper Boone limestone forms a long outcrop; the bed is composed of shaly, flaggy and lenticular bedded limestone, some of which near the top and especially along parting planes is decidedly arenaceous. Archimedes are abundant in the upper part of these limestones. Along a little brook, one mile to the west of Big Cabin creek, a full section of the limestone overlying the Boone chert is exposed. The limestone bed is about thirty feet thick and arenaceous throughout, though it varies very much in the proportion of sand and lime in different strata. The beds that are most arenaceous are shaly and lenticular and some contain arenaceous limestone nodules with flinty centres. Archimedes occur in some of these strata. East of Grand river, opposite Chouteau, this bed is arenaceous and flaggy. About seven miles east of Adair the Boone limestone outcrops along streams. The rock is massive, hard, gray, fossiliferous limestone. The outcrops seen northeast of Ft. Gibson, west and southwest of Tahlequah, are practically all gray limestone in rather massive strata. The bed as it occurs along the Illinois river and Greenleaf creek southeast of Greenleaf, is about thirty feet thick, mostly gray and massive limestones. There is at the top of the bed, however, a stratum of bluish limestone which weathers to a whitish color, and the base of the bed is somewhat arenaceous, shaly and wavy.

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[1] *Ann. Rept. Geol. Surv. Ark.*, 1890, Vol. iv, p. 253.

Along Walkingstick creek, about three miles north of Marble, the stratum is thirty feet thick, and is composed of massive gray limestone. The top of this bed, as seen in the base of a hill one and a half miles south of the Tahlequah-Evansville road and four or five miles east-southeast from Wauhillau, has a little blue limestone that weathers white. Near the base it is decidedly arenaceous and shaly; the rest of the bed, which is the greater part of it, is massive gray limestone as usual. East of Stillwell, south and southwest of Westville, the stratum is from thirty to forty feet thick, and is practically all gray limestone in layers from a few inches to five or six feet in thickness.

## FAYETTEVILLE SHALE.

The Fayetteville shale is probably the stratigraphic equivalent of the Warsaw division, as recognized in Illinois, Iowa, etc.

Secs. a–k, Pl. V, show the variation in thickness and the associated strata of the Fayetteville shale along its line of outcrop through the Indian Territory. These sections were made at the following localities:

Sec. a—About two miles west and southwest of Stillwell.

Sec. b—Four or five miles east-southeast from Wauhillau and one and a half miles south of the Evansville-Tahlequah road.

Sec. c—Compiled from sections made northwest of Marble and southwest of Bunch.

Sec. d—West side of Big Vian creek about one and a half miles northwest of Vian.

Sec. e—Compiled from outcrops along the Illinois river and Greenleaf creek, about five miles east-southeast from Greenleaf.

Sec. f—About one mile north of Fourteen Mile creek and one and a half miles northeast of Grand river.

Sec. g—About two and a half miles south-southwest of Markhain's store or thirteen miles south of Brushtopped mountain.

Sec. h—One and a half miles east of Grand river, opposite Ned Adair's ferry, east of Chouteau.

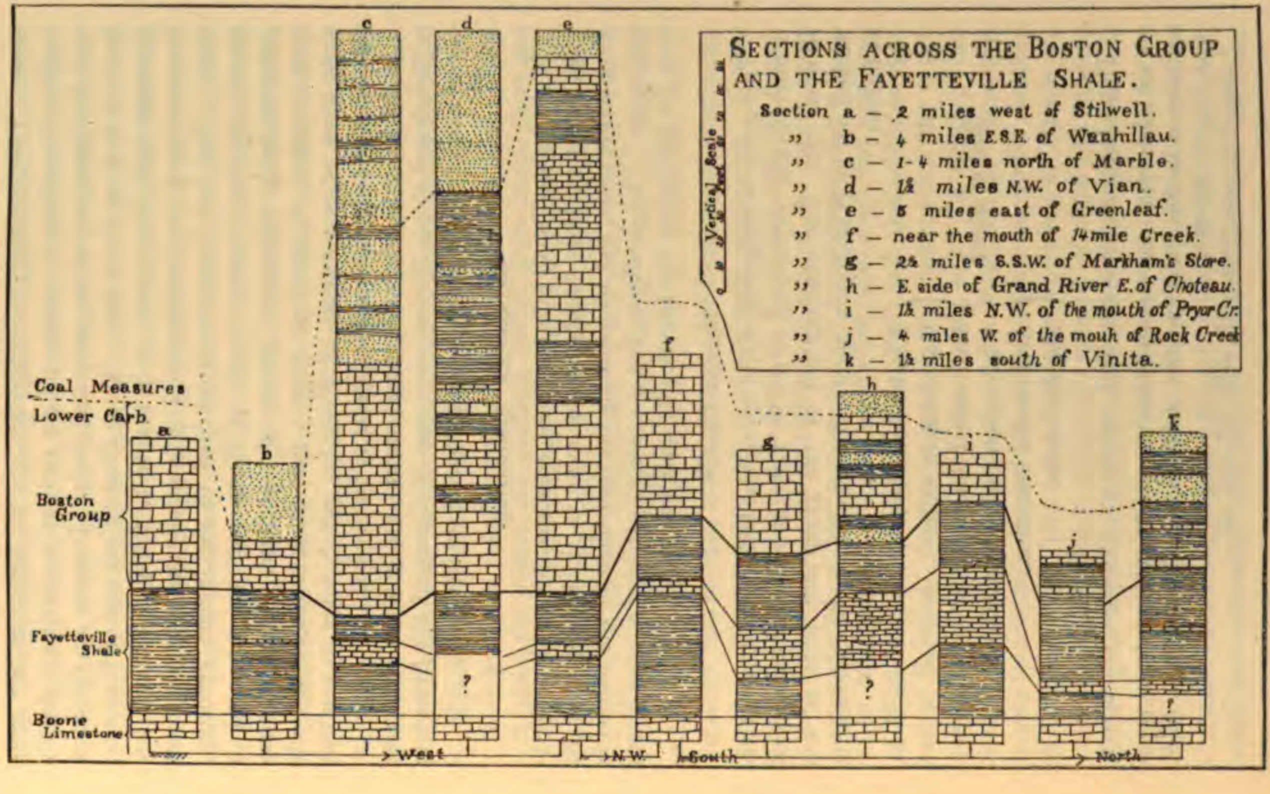
Sec. i—Brushtopped mountain, a small hill one mile north of Pryor creek and one and a half miles west of Grand river.

Sec. j—South side of Rock creek about four miles west of its mouth northeast of Adair.

Sec. k—Along and south of Little Log Cabin creek one and a half miles south of Vinita.

The Fayetteville shale is a black, friable, clay shale, which usually contains clay-ironstone concretions, and has an average thickness of about fifty feet. This shale immediately overlies the upper Boone limestone, and varies but little around the southern and the southwestern border of that limestone, and also along the western border as far north as the Grand river east of Chouteau. Farther to the northward it is more arenaceous and thinner and varies in color from gray to blue and yellowish. It is doubtful whether there are any outcrops as far north as the Indian Territory-Kansas line that may be referred to this shale. The shale is divided throughout by a bed of light blue, friable, fine-grained lime-

*Plate V.*



SECTIONS ACROSS THE BOSTON GROUP AND THE FAYETTEVILLE SHALE.

Section a — 2 miles west of Stilwell.
" b — 4 miles E.S.E. of Wauhillau.
" c — 1-4 miles north of Marble.
" d — 1½ miles N.W. of Vian.
" e — 5 miles east of Greenleaf.
" f — near the mouth of 14 mile Creek.
" g — 2½ miles S.S.W. of Markham's Store.
" h — E. side of Grand River E. of Choteau.
" i — 1½ miles N.W. of the mouth of Pryor Cr.
" j — 4 miles W. of the mouh of Rock Creek
" k — 1½ miles south of Vinita.

stone. The lithologic characteristics of this limestone are quite uniform throughout its extent and are such as to contrast it sharply with the limestones of the associated beds. It varies in thickness from an inch to thirty feet. Along Grand river east of Wagoner, Chouteau and Pryor creek, it is twenty to thirty feet thick; farther northward and southeastward it is usually but five to ten feet thick. This bed is apparently confined to the Indian Territory, since it was not observed north of Vinita and was not noted in Arkansas by the Geological Survey of that State. There is, however, a stratum of limestone about a foot thick in the Fayetteville shale three miles southeast of Westville, which from its position and lithologic characteristics, appears to be this bed.

In the Fayetteville shale exposed around the hillsides southwest of Bunch and along Illinois river east of Greenleaf this limestone occurs almost regularly and is usually five or six feet thick.

## BATESVILLE SANDSTONE.

In the isolated small hills northwest, southeast and south of Westville, sandstone beds twenty feet or more in thickness overlie the Fayetteville shale, and are probably the equivalent of the Batesville sandstone. This sandstone bed is apparently lacking at other places over the field where the Fayetteville shale was seen.[1]

## BOSTON GROUP.

This group is composed of the uppermost beds of the Lower Carboniferous and corresponds to the St. Louis and Chester horizons of Illinois, etc. The classification of the group into beds as was worked out in Washington county, Ark., by Dr. F. W. Simonds[2] is as follows:

Boston group
- Kessler limestone.
- Coal-bearing shale.
- Pentremital limestone.
- Washington shale and sandstone.
- Archimedes limestone.
- Marshall shale.

These horizons were classified mainly on lithologic characters, which change rapidly in most of them. These variations are apparently greater in the Indian Territory than they are in Arkansas. In the northern part of the Indian Territory it is doubtful whether the group is represented by any deposits of consequence. It is represented southeast of Vinita by a series of shaly clays and thin beds of impure limestones, aggregating about seventy-five feet in thickness. East of Chouteau, along Grand river, the group is about one hundred feet thick and is rather clearly divided into different beds of limestones and shales. On Salisaw creek and eastward to the Arkansas-Indian Territory line, the group is about one hundred and fifty to two hundred feet thick. The whole group, as outlined in Washington county, Ark., is, however, nowhere in the area studied represented in a characteristic way. The Archimedes and Pentremital limestones are usually together, and it is very doubtful whether the Kessler limestone is at all represented.

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[1] Mr. Stuart Weller has recently shown that the Batesville sandstone is the equivalent of the Aux Vases sandstone of Illinois and Missouri (*Trans. N. Y. Acad. Sci.*, xvi, 251–282).

[2] *Ann. Rept. Geol. Surv., Ark.*, 1888, Vol. iv, p. xiii.

This group is usually confined to an escarpment and isolated hills along the western and southern border of the Boone chert and limestone area; at most its outcrop forms a belt only two or three miles wide along the border of the Lower Carboniferous. Secs. a–k, Pl. V, show the development of this group along its line of outcrop from near Stillwell to near Vinita. The hills east, west and south of Stillwell are capped by fifty to seventy-five feet of limestone that belongs to this group. The limestone is usually gray in color, rather massive and in places quite arenaceous. Farther westward, in the isolated hills south of Wauhillau, near the Evansville-Tahlequah road, the limestone and beds of the Boston group are considerably thinner and are overlain by sandstone that is probably Coal Measures. Ten to twenty-five miles south and southwest of Wauhillau, near Bunch, Marble, Vian and along Illinois river east of Greenleaf, the Boston group is one hundred and fifty to two hundred feet thick and probably thicker, since the dividing line that has been used to separate this group from the Coal Measures is largely an arbitrary one and the doubtful beds are mostly classified as Coal Measures. One and a half miles northwest of Marble the lower part of the Boston group beds consists of about one hundred feet of gray limestone slightly interstratified with clay shale and arenaceous shaly limestone. Archimedes occur frequently in the lower part of the limestone bed. Overlying this limestone there is a series of strata aggregating about two hundred feet in thickness, which are composed of sandstones and some interstratified clay shale.

The sandstones vary from massive to flaggy and shaly, and in places near and at the top they grade into a grit. This grit appears to be the equivalent of the so-called Millstone grit of the Geological Survey of Arkansas, since it has the same lithological characteristics and apparently has the same stratigraphic position. It is probable, therefore, that not over one hundred feet of the shales and sandstones overlying the limestones at this place should be referred to the Boston group. The above section (Sec. c, Pl. V), with slight modifications, represents the group as it is shown in outcrops between Bunch and Marble.

The Boston group is well exposed along the west side of Big Vian creek, northwest of Vian, where Sec. d, Pl. V, was made. The section at that place is as follows:

| | FEET. |
|---|---|
| Massive sandstones (Coal Measures ?) | 100+ |
| Arenaceous black clay shale | 75 |
| Brownish, weathering, hard limestone | ½ |
| Shaly sandstone | 5 |
| Gray, massive, hard limestone | 5 |
| Black clay shale | 10 |
| Massive, hard, gray limestone at the base which grades into shaly brownish weathered limestone at the top | 15 |
| Clay shale (?) | 10 |
| Massive, gray, firm, fossiliferous limestone | 35 |
| | 135½ |

The following is a section on the east side of Illinois river, about west-northwest of Marble:

| | FEET. |
|---|---|
| Sandstone and grit (Coal Measures?) | 30+ |
| Blue clay shale | 5 |
| Uniformly textured, smooth, gray limestone in strata 1 to 2 feet thick | 10 |
| Nodular friable limestone in thin, irregular, rough-surfaced strata with clay partings and fillings of lenticular places through the strata | 10 |
| Rather uniformly textured, massive, gray, fossiliferous limestone | 50 |
| Blue clay shale | 20 |

| | FEET. |
|---|---|
| Hard, gray limestone | 2 |
| Sandstone and clay shale | 10 |
| Limestone, usually massive, arenaceous, and friable, but it varies to pure, tough limestone of a gray color. Some bluish limestone, which weathers to a white color, occurs near the base of the bed | 30 |
| | 137 |

Below this section is about twenty feet of the Fayetteville shale and its included stratum of blue limestone. The limestone at this place is only about two feet thick.

On the west side of Illinois river, about five miles east-southeast from Greenleaf, the following section (Sec. c, Pl. V) may be seen:

| | FEET. |
|---|---|
| Sandstones and grit (Coal Measures?) | at top |
| Massive, gray, brownish weathering limestone | 15 |
| Clay shale | 20 |
| Massive gray limestone | 4 |
| Blue limestone alternating with a little clay shale. The limestone weathers to a rather smooth but angular wavy surface and a whitish or yellowish color; the weathered cross sections of fossils and wavy branching calcite seams of a darker color than the mass of the rock gives a streaked, wavy and mottled appearance to its surface | 30 |
| Rather massive but in part flaggy limestone which in places contains abundant Pentremites | 50 |
| Clay shale | 25 |
| Gray massive limestone | 75 |
| | 215 |

The following section is exposed four miles southeast of Ft. Gibson on the south side of Bayou creek along the Ft. Gibson-Braggs road:

| | FEET. |
|---|---|
| Sandstone (Coal Measures) | at top |
| Massive gray limestone | 10 |

| | FEET. |
|---|---|
| Argillaceous sandstone, sandstone shale and arenaceous clay shale | 20 |
| Limestone: the lower part is brownish weathering and somewhat shaly, the upper part is massive and gray | 20 |
| Sandstone | 5 |
| Limestone | 5 |
| Sandstone | 5 |
| Limestone containing Archimedes in the central part of the bed | 50 |
| | 115 |
| Fayetteville shale and some interstratified blue limestone | at base |

West and northwest of Tahlequah, along Pecan creek and Fourteen Mile creek, and along Grand river, east and northeast of Wagoner, the Boston group is usually limited to a fifty to seventy-five foot bed of limestone, which is in places slightly interstratified with clay and contains Archimedes and Pentremites associated throughout almost the entire bed. The Archimedes, however, are more common in the central and lower divisions, while the Pentremites are more common in the central part of the bed. Farther to the north it becomes thinner and more argillaceous until calcareous and arenaceous clays form the principal part of the group as shown in Secs. j and k, Pl. V. East of Pryor creek, Adair, Big Cabin, and south of Vinita, the group is represented by yellowish calcareous clays, friable arenaceous limestones, some hard gray limestone and a little sandstone. The limestone and clays are usually rich in fossils. The following section (Sec. k, Pl. V) will show the general character of the group along its outcrops from the Grand river, east of Chouteau, to within one and a half miles of Vinita.

| | FEET. |
|---|---|
| Brownish weathering massive sandstone (Coal Measures?) | 5 |
| Clay shale (Coal Measures?) | 10 |
| Sandstone (Coal Measures?) | 12 |
| Coal Measures | 27 |

| | FEET. |
|---|---|
| Clay shale which contains some fossiliferous shaly limestone near the base | 10 |
| Friable arenaceous fossiliferous limestone | 2 |
| Calcareous, fossiliferous, yellowish clays | 10 |
| Hard, rough-surfaced, highly fossiliferous limestone | 3 |
| Bluish clay shale | 25 |
| Limestone | 1 |
| | 51 |
| Clay shale (Fayetteville shale ?) | at base |

Fossils of a decided Coal Measures facies were collected from some black clay shale at a place on the M. K. & T. Railway, about four miles north of Vinita. This shale is not more than one hundred and fifty feet above the Boone limestone, so the strata referable to the Boston group, at this place, is probably not more than twenty-five or fifty feet thick.

Between Fairland and Miami the strata that may be referred to this group are gray shales and possibly a little limestone. Northeast of Miami it seems probable that the horizon of the Boston group is overlapped by Coal Measures shales and sandstones, or if this is not the case the group is represented by gray clay shales and some sandstone.

The sections of the Boston group show that it is thicker and apparently has higher beds in the southwestern part of the Lower Carboniferous area where the strata are exposed by being folded or excessively eroded. The same sandstone or grit bed appears to overlie unconformably these different Lower Carboniferous beds at various places. The sandstone beds lying on the Boston group one and a half miles south of Vinita are apparently the same sandstones that rest on the Boone limestone, some six or seven miles southeast of Vinita. Two or three miles southwest from the mouth of Pryor creek a conglomerate sandstone overlies the Boston group to the westward and the Boone limestone to the eastward. The gradual upward change in the Lower Carboniferous deposits from massive and extensive cherts and limestones to shales, arenaceous limestones and sandstones indicate an upward movement of the ocean bottom. This movement may have continued until the deposited beds were subject to slight erosion before the following subsidence began and the sand and grit deposits laid down over them. The continuity of the fauna and the small amount of overlapping in these deposits could, however, allow only a slight break in deposition.

## COAL MEASURES.

The Coal Measures of the Indian Territory and Oklahoma are a direct continuation of the Kansas, the Arkansas and apparently the Texas Coal Measures. The southward extension of the Coal Measures of Kansas enters the Indian Territory in a belt sixty-five miles wide, which extends from about ten miles west of the northeast corner of the Territory to near the northwest corner. The western limit of this belt through the Territory bears about 10° west of south throughout the area studied. The eastern limit running southward from the Kansas-Indian Territory line extends south 40° W. for a distance of forty miles, then runs nearly south for fifty miles and then with a gentle southward curve and zigzag line extends eastward into Arkansas. The belt through the Territory, therefore, at first contracts from the eastern side for a distance of nearly one hundred miles, then rapidly widens on the eastern side so that the Coal Measures in the territory studied, roughly covers an L-shaped area. The southward continuation of the Coal Measures into Texas is broken in the southern part of the Indian Territory by the overlapping of Cretaceous deposits.

*Structure.*—The Coal Measures lie in the three structural and topographic groups previously mentioned. The horizontally uplifted plateau, or Ozark type, includes the larger part of the Coal Measures lying between the southern boundary of the Lower Carboniferous area and the northern boundary of the Arkansas river valley. The area of the folded beds, or Ouachita type of structure, lies principally south of the Arkansas river and east of a line connecting the mouth of the Canadian river, Brooken, and a point about seven miles west of McAlester. The remaining and by far greater part of the Coal Measures in the area under discussion belongs to the Prairie Plains region, and consists of gently westward and northwestward dipping strata.

*Stratigraphy.*—With the possible exception of slight uncomformities produced by overlapping of the basal beds of the Lower Coal Measures, there seems to be no break in the stratigraphy from Lower

Carboniferous into Permian beds. A rough estimate gives a total thickness of 25,000 feet for the Coal Measures deposits. Most of these strata were laid down near shore and are, therefore, subject to the irregularities of near-shore deposits. Arenaceous clay shales, sandstones, limestones, coal, grits and conglomerates occur in relative abundance in the order named. Well-marked beds that may be used for making stratigraphic divisions are for the most part wanting. The limestone beds are mainly confined to the northern part of the field and to the central part of the Upper Coal Measures. The shale and the sandstone beds are so local and repeated in such lithological uniformity that they serve poorly for divisions; fossils, especially in the southern part of the field, are of rare occurrence. The larger coal beds, with some irregularities, extend across the entire field and furnish the best means of grouping the formations. The workable beds of coal are all confined to the lower part of the Upper Coal Measures. The Coal Measures deposits will be considered under the following classification:

- Coal Measures.
  - Upper Coal Measures.
    - Poteau group.[1]
    - Cavaniol group.[1]
  - Lower Coal Measures.

Plates II and VII show the relation of these groups.

The Lower Coal Measures produce no coal; the Cavaniol group contains the workable beds, and the Poteau group contains some thin ones.

## LOWER COAL MEASURES.

There are three different areas of the Lower Coal Measures in this field. One lies in the southeastern part of the region, and is bounded on the north by a line running along the southern base of the Poteau mountains and the north side of Fourche Melane valley and Jack Fork mountains; from the latter place the bounding line runs southwesterly and passes out of the field. This area includes the Fourche Melane valley and the upper part of the Kiamichi valley and Walker, Black Fork, Rich, Blue, Windingstair, Jack Fork and Kiamichi mountains and the intervening areas.

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[1] These names were taken from the names of mountains in the southeastern part of the field where the beds included in those groups are well represented.

The second area is a strip about four miles wide and twenty-two or twenty-three miles long which extends into the Territory along the Backbone anticline. The third one is an irregular belt bordering the Lower Carboniferous on the south and west. The most of the southern part of this belt lies near and to the north of the Arkansas river, and includes the Boston mountains; the western part of the belt extends along the Missouri, Kansas and Texas railway from Wagoner to Vinita, and from Vinita it runs northeasterly, passing into Kansas at and southwest of Baxter Springs. Along the Arkansas-Indian Territory line this belt is about twenty miles wide, but it gradually narrows to the westward and northwestward until north of Wagoner it is usually but four to five miles wide.

*Lithology of the Lower Coal Measures.*—Throughout this group there is such a constant repetition of arenaceous gray, clay shales and sandstones of uniform character that the lithology and stratigraphy are exceedingly monotonous.

There is, however, some marked variation introduced by the grits and conglomerates at the base of the group north of the Arkansas river, and by the limestones south of Ponola, Wilburton and Hartshorne. Some minor variations in color and composition also occur in the shales and sandstones. The sandstones are usually massive, but in places they are flaggy or shaly and micaceous, argillaceous, calcareous, ferruginous, or bituminous. A little quartzite occurs in the Windingstair mountains and some conglomerates may be seen in the vicinity of Thomasville.

*Thickness of the Lower Coal Measures.*—The greatest thickness observed in the Lower Coal Measures was in the southeastern part of the field. In this locality the strata throughout show little variation; extensive faults lie along the north side of Walker, Black Fork, Windingstair and Kiamichi mountains, and smaller faults at other places; and overthrows occur at some places to further complicate the interpretation of the stratigraphy. On account of these difficulties, as well as the limited amount of work the reconnaissance would allow, only rough estimates of the thickness of the exposed beds will be attempted.

The longest continuous section studied in this part of the field was from the base of the Poteau mountains to the south side of Rich mountains. This section extends north and south about three or four miles west of the Arkansas-Indian Territory line. The stratigraphy somewhat generalized along this line is shown in

Sec. 8 (p. 366.) The strata exposed along this section are divided into three divisions by two faulted areas. The division on the north is about seven thousand feet thick, the one next further to the south is about eleven thousand feet thick, but possibly contains as much as six thousand feet of strata that is repeated from the first division, thus leaving only five thousand feet to be added to the seven thousand of the first division, which gives twelve thousand feet. The third and last division is about fifteen thousand feet thick. In this the heavy sandstone beds in the south side of Black Fork and Rich mountains are each about one thousand feet thick, and are so much more massive than any of those exposed to the north, that they are probably lower horizons. There is a strong probability, however, that the strata of Black Fork and Rich mountains are the same, which is the case if the beds are overthrown to the north, as they appear to be. If this is the case, only five thousand feet of the thickness of the strata of the two mountains, should be added to the section already estimated. The remaining five thousand feet of strata to the north of Black Fork mountain is most likely a repetition of the strata exposed and counted farther to the northward. So only five thousand feet more can safely be added to the twelve thousand feet, which gives a total thickness of seventeen thousand feet.

It is possible that this section represents a thickness of as much as twenty-five thousand feet of strata, but under the observed conditions, seventeen thousand feet seems more probable, and even that may be too much. The base of the formation was not seen, but as the thickness exposed is very nearly as much as the estimated thickness of the whole formation in Arkansas,[1] it is probable that almost the total thickness of the beds is exposed in this section. The Lower Coal Measures in Arkansas, however, run a little higher in the section than they do in the Indian Territory, since the Huntington Coal belongs to a higher horizon than the coals farther to the east in Arkansas.[2]

*Stratigraphy of the Lower Coal Measures.*—The basal beds of the Lower Coal Measures appear to be exposed only in the Cherokee Nation. Overlying the Lower Carboniferous there is a series of sandstones, grits and shales which belong to the basal beds of the Coal Measures. No definite division between the Lower Carboniferous and the Coal Measures could be fixed, but the fossils found in the highest strata, known to belong to the Boston group, are a mingling of species belonging to the highest Lower Carboniferous and the Coal Measures. These sandstones, grits and shales have the same lithological characteristics and stratigraphic position as the so-called Millstone grit of the Geological Survey of Arkansas.[1] There is every gradation from the smooth, fine-grained sandstones to the grits and coarse conglomerates. Good examples of the grit may be seen, north of Camp Track, five miles south of Bunch, in places three to four miles northwest of Vian, and along the east side of Illinois river west-northwest from Marble. This grit is composed of angular grains of quartz, which are usually from one to two millimetres in diameter, but occasionally are from five to six millimetres in diameter. Hematite usually forms the cementing matter for the grit. The basal group of the Lower Coal Measures in the Cherokee Nation is composed mainly of sandstones and grits throughout. No section was made of this group along the Arkansas-Indian Territory line, but it is probably not less than two thousand feet thick. Five to ten miles southeast of Ft. Gibson it is three hundred feet thick; from eight to ten miles northeast of Ft. Gibson it is about two hundred feet thick. From this place further to the north it rapidly thins until from about ten miles north of Wagoner to near Baxter Springs, Kans., it is but five to fifteen or twenty feet thick. In this northern part of the field the grit is usually lacking and the sandstones are very variable. These basal sandstones cap the isolated hills and east-facing escarpments from four to six miles south of Chouteau, one and a half miles south of Vinita, three miles west of Afton, one mile south of Miami, and about two miles south of Baxter Springs, Kans. There is a bed of gray, arenaceous clay shale two hundred and fifty to three hundred feet thick overlying this group of sandstones and grits throughout the Cherokee Nation. This shale is somewhat thicker in the northern part of the field than it is toward the south. It comprises nearly all the Lower Coal Measures strata that lie west of Grand and Spring rivers and throughout that area it is marked by level or gently undulating prairie plains.

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[1] Dr. Branner estimates the thickness of these Lower Coal Measures in Arkansas to be 18,480 feet thick (*Amer. Jour. Sci.*, Vol. ii, September, 1896, p. 235)

[2] *Geol. Surv. of Ark.*, Ann. Rep., 1888, Vol. iii.

The southern extension of the Lower Coal Measures area of the Cherokee Nation outcrops along the Milton-Bokoshe anticline south of the Arkansas river. The rocks exposed along this anticline are mainly sandy clay shales north of Bokoshe, and massive and flaggy sandstones east and west of Milton. The sandstones one mile south of Bokoshe are highly micaceous and often smooth-surfaced flags. About two thousand feet of Lower Coal Measures rocks are exposed on either side of the anticline in this locality.

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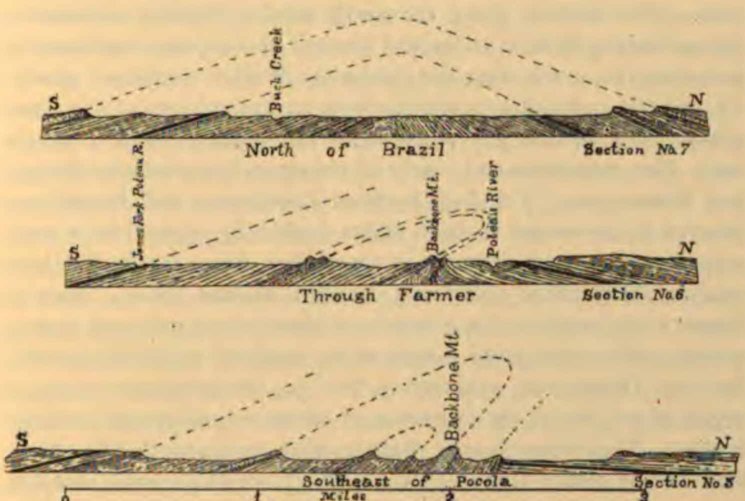
[1] *Ibid.*, Vol. iv, p. 106, and 1890, Vol. i, pp. 113–115.

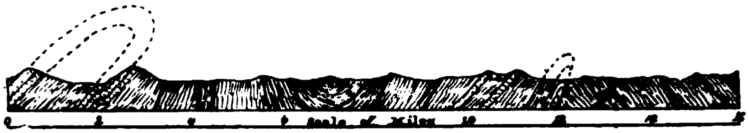
In the Backbone mountain area of the Lower Coal Measures the beds are massive sandstones and thick gray arenaceous clay shales. The sandstone beds are from about thirty to five hundred feet in thickness and the interbedded shales are from eight hundred to thirteen hundred feet in thickness. The structure of the Backbone ridges that best account for the observed facts is shown in Secs. 5, 6 and 7, Pl. VI and in Pl. I. This overthrown anticline is faulted along the north side of the overthrow. The faulting runs westward from Arkansas almost to the western end of the mountains, where it ends rather suddenly. With the gradual lessening of the faulting toward the west the strata on the north side of the fault line increase in dip as they approach the axes of the anticlinal folds. The thickness of strata exposed in this area, on either side of the anticline, is a little over twenty-five hundred feet. The Lower Coal Measures in the southeastern part of the field show very little

*Plate VI.*



Sections across the Backbone anticline.

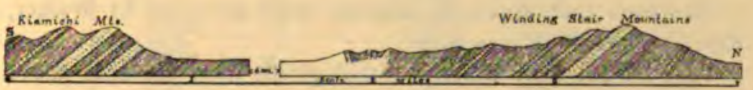
variation lithologically from the beds described to the northward; there is, however, a great increase in the thickness of the deposits. The east and west folding in this area has made it possible to get moderately long exposures of the same strata along the axial direction of the folds. The three groups of strata shown in Sec. 8 are, with modifications, extended to the westward the full length of the area. The faulting along the north side of Walker mountains, along Fourche Melane valley and south of Hartshorne, separates the group on the north from the Central or Walker mountain group. The central and southern groups are in part repetitions of the same strata. The second group comprises the strata of Walker mountains, Blue mountains and nearly all the strata lying between Bengal and Hartshorne. The beds between Hartshorne and Bengal are referred to the second division rather doubtfully, since this necessitates an upthrow of about six thousand feet along the faulted belt south of Hartshorne and along Fourche Melane valley. Such a throw would require the strata in a block about one and three-quarter miles wide to be tilted at an angle of 45° to the south. South of Hartshorne, as shown in Sec. 10, the strata are tilted at angles of 40° to 50° for a distance of about two miles and possibly farther. This tilting is only slightly offset on the north side of the fault line by gentle dips of 4° to 5°. So it seems probable that the throw is as much as six thousand feet at this place. South of Wilburton and southwest of Red Oak the strata on the south side of the Fourche Melane valley do not dip very much more steeply than they do on the north side, and as the dips are in opposite directions the beds appear to be the same. They are, however, not the same, for the coal beds are not repeated on the south side of the valley. Furthermore, the strata are different lithologically, since limestones occur on the south side and may be traced westward to the limestone beds south of Hartshorne, which beds have been shown to probably belong six thousand or seven thousand feet below the



Sec. No. 8. Across the Lower Coal Measures, south of Poteau mountain.

Grady coal bed. The third division comprises the strata of Black Fork, Rich and Windingstair mountains.

The highest bed of the Lower Coal Measures is a sandstone about one hundred and fifty feet thick, although varying in thickness from a few inches to three hundred feet. Mr. H. M. Chance calls it the Tobucksy[1] sandstone. This bed is especially important because it immediately underlies the Grady coal bed and makes a ridge of considerable prominence almost all along its line of outcrops, so that the coal may be closely located by tracing the outcrop of this sandstone. It has an unusual persistence for a sandstone, outcropping as it does almost regularly over an area of one thousand square miles, and forming an unbroken ridge excepting at a few places where streams have cut across it, from about three miles northwest of Heavener to Hartshorne. This ridge is a very prominent topographic feature rising usually one hundred to three hundred feet above the surrounding country. South and southwest of Heavener and southwest and west of Milton, this bed is thick and makes ridges from one hundred to three hundred feet high. Where it is thick enough to make a prominent topographic feature it is shown so on the sketch map. The following are approximate sections of the upper part of the Lower Coal Measures as they occur in Secs. 8 and 5; the sections were made south and southeast of Heavener and across the Backbone anticline.



Sec. No. 9. Across the Winding Stair and the Kiamichi mountains, south of Hanson creek.

| | SEC. 8.<br>FEET. | SEC. 5.<br>FEET. |
|---|---|---|
| Sandstone | 200 | 50 |
| Gray arenaceous clay shale | 1000 | 1150 |
| Massive sandstone | 50 | 250 |
| Gray arenaceous clay shale | 660 | 600 |
| Sandstone | 30 | 35 |
| Clay shale | 1150 | 500 |

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[1] *Trans. Am. Inst. Min. Eng.*, Vol. xviii, p. 659.

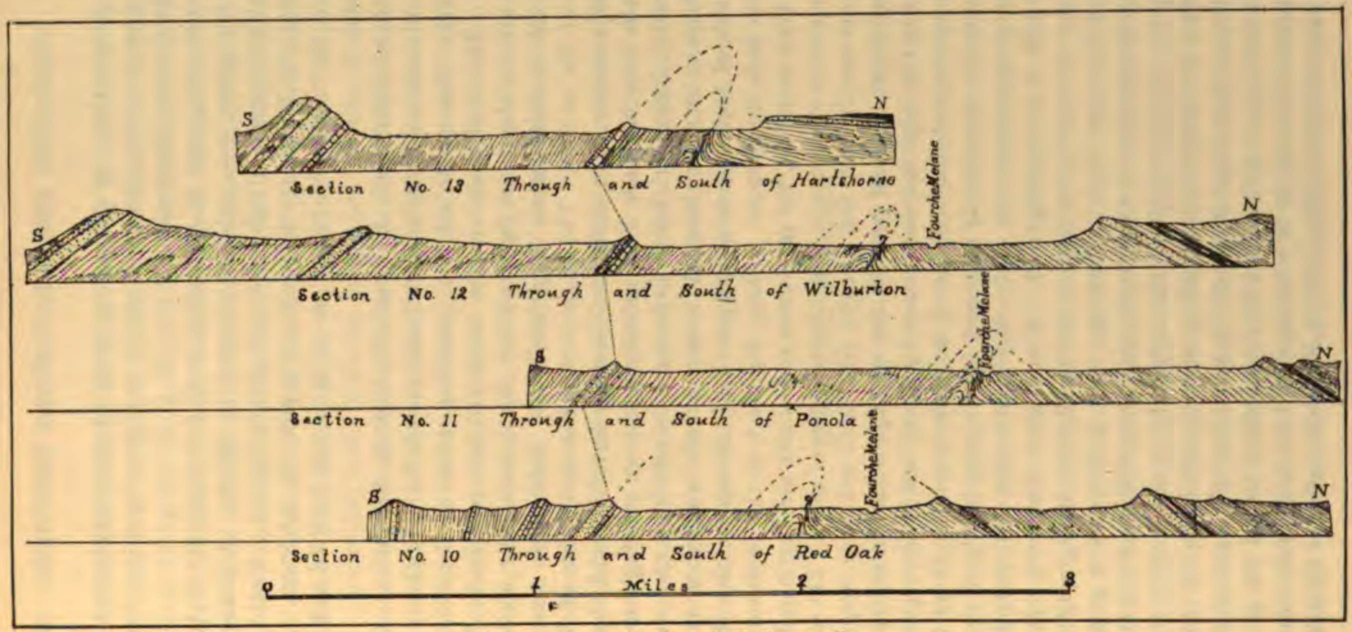
| SEC. 8. | FEET. |
|---|---|
| Sandstone | 10 |
| Shale and thin beds of sandstone | 800 |
| Sandstone | 10 |
| Shale and thin beds of sandstone | 800 |
| Sandstone | 10 |
| Shale and thin beds of sandstone | 2000 |

The beds that appear to underlie these are those of Walker, Blue and Jack Fork mountains.

They are but little different lithologically from the beds above them, but the shales are of a darker color, and in the western part of the belt there is some limestone to break the usual monotony. The main ridges of Walker, Blue and Jack Fork mountains have sandstones from fifty to one hundred feet or more in thickness in the southern part of the ridges.

Secs. 10, 11, 12 and 13, Pl. VII, show the general character and variation of the rocks on the south side of Fourche Melane valley from a point south of Red Oak to a point south of Hartshorne. Sec. 10 lies south of Red Oak. The limestone, calcareous sandstone and arenaceous limestone shown in this section were seen southwest of Red Oak, but they probably extend farther to the east. In this section the first sandstone bed south of Fourche Melane is about one hundred feet thick, usually massive. Twenty to thirty feet of arenaceous limestone and calcareous sandstone occurs on the north side, or at the base of this sandstone bed. The next ridge to the south is formed by two sandstones each ten to fifty feet thick and separated by about fifty feet of clay shale. This shale southwest of Red Oak is partly replaced by five to ten feet of hard, rather nodular, blue limestone. On the north side of the fourth sandstone—the third prominent ridge south of Fourche Melane—there is more arenaceous limestone and calcareous sandstone. It is only five to ten feet thick at the places where it was seen. Farther west or south of Ponola, Sec. 11 shows the stratigraphy of the first ridge south of Fourche Melane. At this place the strata dip south 50°. There is a hard, blue limestone, fifteen to twenty feet thick, on the south side of the ridge; this limestone is underlain by about one hundred and twenty-five feet of sandstone, of which the upper fifty feet is ferruginous and fossiliferous, and the lower part is hard massive sandstone. This sand-

Plate VII.


S
N
Section No. 13 Through and South of Hartshorne
S
N
Fourche Melane
Section No. 12 Through and South of Wilburton
S
N
Fourche Melane
Section No. 11 Through and South of Ponola
S
N
Fourche Melane
Section No. 10 Through and South of Red Oak
0
1
Miles
2
3

Sections across the Fourche Melane valley.

stone is underlain by alternating strata of shaly sandstones and arenaceous clay shale, which in turn is underlain by thirty feet of gray fossiliferous limestone.

Farther west, south of Wilburton, only one limestone bed was seen, but others are probably covered by débris. A somewhat generalized section at this point is shown in Sec. 12. Farther to the west the limestone beds increase rapidly in thickness, until south of Hartshorne the lowest one is about one hundred and fifty feet thick.

*Strata of Black Fork, Rich and Windingstair Mountains.*—Massive sandstones with regular texture and smooth bedding planes and dark gray clay shales are the prevailing rocks of these mountains. The sandstones in the southern part of Black Fork mountain are about one thousand feet thick, principally massive, and light in color; some flaggy and shaly beds occur near the centre of the section. The sandstones of the south side of Rich mountain appear to be about one thousand feet thick and closely resemble those of Black Fork mountain, but are seemingly somewhat more flaggy and have a little more interbedded clay shale. The strata in the valley between the two mountains and those in the north side of both mountains are principally arenaceous clay shale and thin beds of sandstone. Along Big creek on the north side of Black Fork mountain, the sandstones and shales are distributed in the proportion of about one of sandstone to five of shale. The sandstones are usually from four to eight feet thick and have irregular bedding planes. About one mile east of Page a massive sandstone about fifty feet thick is broken across by a fault and so impregnated with bitumen that the rock has a very black color. There is a small anticline immediately southwest of this point in Big creek.

These irregularities seem to be only local breaks and crumplings on the side of a very large fold. Windingstair mountains appear to be the westward continuation structurally and stratigraphically of Black Fork and Rich mountains. Sec. 9 shows in a general way the stratigraphy of the Windingstair mountains south of Hanson creek. The north side of the mountains at this point is steep and rather free from ridges or cañons running parallel to the range, while the southern slope is broken by a number of ridges running parallel to the main mountain and less elevated toward the south. Deep erosion channels lie between some of these ridges and connect with a cross channel leading into the Kiamichi valley to the south.

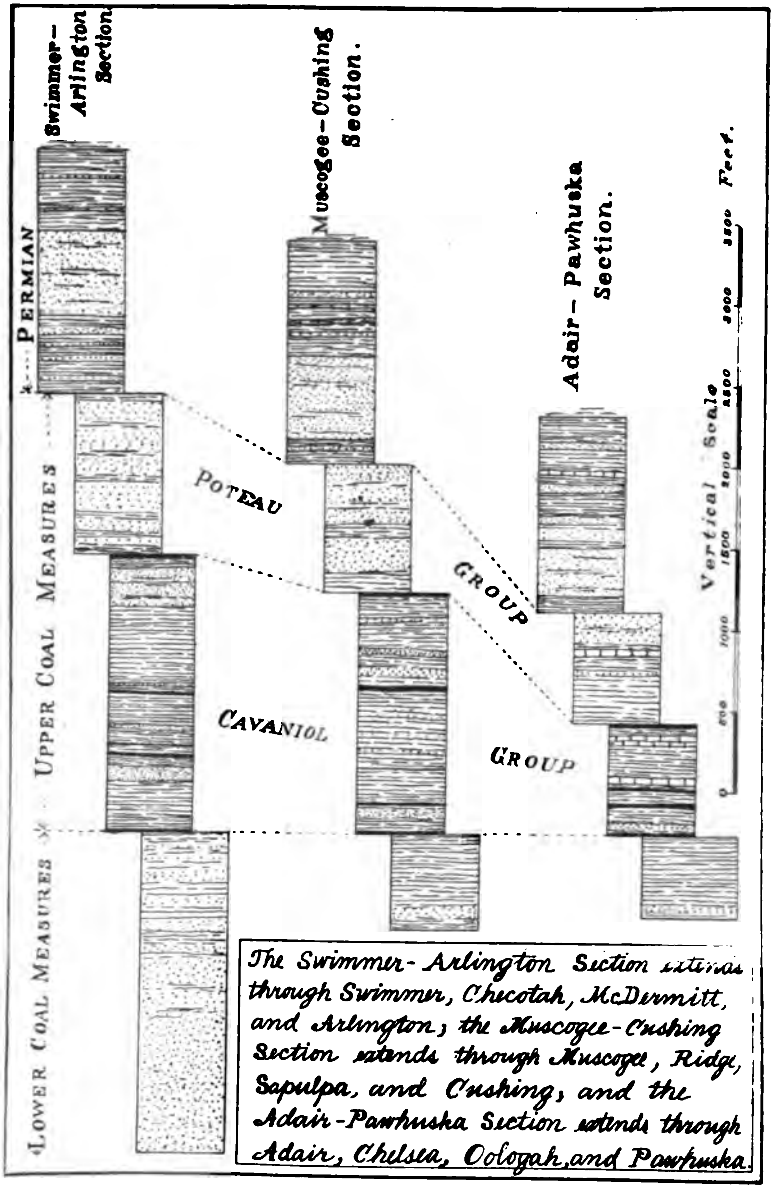
Evidences of faulting and sharp folding may be seen on either side of the mountain along this section, and almost all through the mountain along the St. Louis and San Francisco railway. These orographic movements have metamorphosed the rock locally until the sandstones are quartzites and the shales are hardened. Some limestone concretions and boulders occur in the shales on the north side of the mountain west of the head of Hanson creek and along the railroad four or five miles southeast of Bengal. Occasional chert concretions occur with the limestones. Porous, ferruginous sandstones were found in a number of places on the north face of the mountains and they were usually found to be fossiliferous. The rocks of Kiamichi valley southeast of Talihina appear to be principally dark gray clay shale. Some of this shale that was taken from a well dug at the south side of Windingstair mountain, about ten miles east of Talihina, was almost black and so crushed that every piece showed "slickensides."

The strata of the northern side of Kiamichi mountains bear a close resemblance to and are possibly to be correlated with the massive sandstones of Black Fork mountain, Rich mountain and Windingstair mountain. Sec. 9 shows the structure and approximate stratigraphy of the Kiamichi mountains at the point where they were studied.

## UPPER COAL MEASURES.

*Cavaniol Group.*—This part of the Coal Measures is confined to the area outlined on the map between the outcrops of the lowest and the highest workable coal beds. From Arkansas this coal-bearing belt extends westward into the Territory for a distance of about sixty-five miles and divides into two belts, one of which extends northward and the other southwestward. The belt extending westward from Arkansas lies mainly to the south of Arkansas river and has an average width of about forty miles. The belt extending northward passes through the Creek and Cherokee Nations into Kansas, and has an average width of about twenty-five miles. It lies mainly on the west side of the Missouri, Kansas and Texas railway. The southwest belt extends through the western part of the Choctaw Nation, and has, in the area studied, an average width of about fifteen miles. That part of the Cavaniol group lying to the south and east of Canadian river will be referred

*Plate VIII.*



The Swimmer-Arlington Section extends through Swimmer, Checotah, McDermitt, and Arlington; the Muscogee-Cushing Section extends through Muscogee, Ridge, Sapulpa, and Cushing; and the Adair-Pawhuska Section extends through Adair, Chelsea, Oologah, and Pawhuska.

Comparative sections of the Coal Measures. Compiled from cross-sections through the Cherokee, Creek and Osage Nations.

to as the Choctaw coal field,[1] since this term has been applied to that area by Dr. H. M. Chance.

*Stratigraphy.*—The beds of this group consist of shales, sandstones, coals and limestones. The shales comprise the larger part of the strata, but sandstones are very abundant, especially in the southern part of the field, while limestone beds are confined to the northern part. The workable coals are thicker in the southern region, but extend throughout the entire area. The group is thickest in the southeastern part of the field and thinnest in the northern part. The decrease in thickness appears to run regularly to the westward and northward. The most constant and easily recognizable horizons in this division are the coal beds. Three of these are thick enough over most of the field to work. Other thin beds occur locally, and one in particular that lies about one hundred feet above the central coal bed extends almost regularly throughout the field where its horizon occurs. The lowest workable coal varies in thickness from one and a half to six feet; this is the coal that Dr. H. M. Chance named the Grady coal.[2] It proves to be, without any reasonable doubt, the same bed as the one worked at Huntington, Jenny Lind, Hackett and several other places in Arkansas.

The next higher workable coal is the McAlester bed, which varies in thickness from about one and a half to four feet. The highest workable bed is the Mayberry coal, which also varies in thickness from one and a half to four feet. These three coal beds apparently extend throughout the entire area of the Cavaniol group, but north of the Canadian river there are four coal beds that are worked locally. These four beds were not studied in enough detail to correlate them throughout. The outcrops and stratigraphy noted in different sections across the group give some suggestions of correlation, as may be seen in Pls. I and VIII.

The following table shows a rough estimate of the distance between the coal beds at different places in the Choctaw coal field :

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[1] *Trans. Am. Inst. Min. Eng.*, Vol. xviii, p. 653.

[2] *Ibid.*, 1890, Vol. xviii, pp. 1, 2.

*Vertical Distance between the Grady and McAlester Coal Beds.*

| LOCALITIES. | FEET. |
|---|---|
| One mile east of Fanshaw | 2500 |
| Two miles east of Red Oak | 2500 |
| West of Cameron | 2000 |
| North of Brazil | 2000 |
| South of Milton | 2000 |
| North of Wild Horse Prairie | 1300 |
| East of Krebs | 1000 |

*Vertical Distance between the McAlester and Mayberry Coal Beds.*

| LOCALITIES. | FEET. |
|---|---|
| Cavaniol mountains | 3000 |
| Northeast end of Sans Bois mountains | 2200 |
| West end of Sans Bois prairie | 1500 |

These estimates show a marked tendency throughout the whole division to decrease in thickness towards the west and northwest.

The following sections will show the general stratigraphy of the two lower coal beds and the intervening strata in the Choctaw coal fields:

|  | One mi. west Fanshaw. | West of Cameron. | South side of Buck Creek Prairie. | North side of Buck Creek Prairie. | Northwest of Wild Horse Prairie. |
|---|---|---|---|---|---|
|  | FEET. | FEET. | FEET. | FEET. | FEET. |
| Coal | 1½ | 1½ | 1½ |  | 1½ |
| Shale |  | 1200 |  |  |  |
| Sandstone |  | 10 |  |  |  |
| Shale | 200 | 100 | 200 | 200 | 300 |
| Sandstone | 25 | 10 | 200 | 25 | 50 |
| Shale | 2000 | 300 | 600 | 900 | 400 |
| Sandstone | 50 | 25 | 15 | 25 | 100 |
| Shale | 300 | 400 | 1000 | 1000 | 500 |
| Coal | 3 | 3 | 4 | 4 | 3 |

Two sandstones and three clay shale beds usually form the sequence of strata between the two lower workable coals. This prevailing condition is shown in the above sections. This usual sequence, however, is not constant, for in some places, as northwest of Alderson, only one sandstone intervenes, and in other places, such as west of Cameron, there are three. This table is not intended to show a strict correlation but rather a comparison.

The strata between the McAlester and Mayberry coal beds apparently are more diversified. In the Cavaniol mountains four thick sandstone beds alternating with clay shales intervene between the coals. Northwest of San Bois there are three intervening sandstones, while to the west of Sans Bois two sandstone beds intervene, and east of Brooken only one of prominence lies between the two coal seams. This shows a decrease in the number and thickness of intervening beds to the northwest. The intervening sandstone beds, especially those in Cavaniol and Sans Bois mountains, are usually from fifty to two hundred feet thick and are evenly textured strata that usually have smooth bedding planes, and vary from flaggy to massive sandstone. The first sandstone below the Mayberry coal is especially flaggy and smooth where it was seen on the east end and north side of Cavaniol mountain. The dark gray clay shales interstratified with these sandstones are from two hundred to five hundred feet thick. South of the Arkansas river a coal seam four to eight inches thick occurs almost regularly one hundred feet above the McAlester coal.

A rough estimate of the thickness and stratigraphy of the Cavaniol group north of the Canadian river, along a line running from McDermitt through Checotah and Starvilla to the mouth of the Canadian river, is as follows:

| | FEET. | INCHES. |
|---|---|---|
| Coal | 2 | 6 |
| Gray, arenaceous clay shale | 50 | |
| Friable, shaly and massive sandstone and some clay shale | 300 | |
| Gray, arenaceous clay shale | 500 | |
| Sandstone | 10 | |
| Clay shale | 25 | |
| Coal | | 10 |
| Clay shale | 200 | |
| Sandstone | 25 | |
| Clay shale | 100 | |
| Coal | | 8 |
| Clay shale | 50 | |
| Coal | 1 | 3 |
| Clay shale | 50 | |
| Sandstone and some interstratified clay shale | 100 | |
| Clay shale | 300 | |
| Coal | 1 | 6 |
| Total thickness (approximate) | 1700 | |

A section across the group along a line from Muscogee, through Ridge and Sapulpa to Cushing, is approximately as follows:

| | | FEET. | INCHES. |
|---|---|---|---|
| 1. | Coal (Mayberry coal?) | 2 | |
| 2. | Clay shale | 100 | |
| 3. | Sandstone | 10 | |
| 4. | Shale | 50 | |
| 5. | Thin strata of light gray, arenaceous, limestone and calcareous sandstone interstratified with gray calcareous clay shale | 25 | |
| 6. | Gray clay shale | 100 | |
| 7. | Friable, black, carbonaceous, clay shale, which contains near the top some limestone nodules one and a half feet in diameter. These limestone nodules are carbonaceous and black, but weather to a white color and contain numerous calcite seams running through the nodules | 50 | |
| 8. | Sandstone | 25 | |
| 9. | Clay shale | 100 | |
| 10. | Sandstone | 50 | |
| 11. | Clay shale | 100 | |
| 12. | Coal | 1 | 6 |
| 13. | Gray, arenaceous clay shale containing some thin sandstone strata which are ferruginous in places | 500 | |
| 14. | Coal | | 4 |
| 15. | Clay shale | 250 | |
| 16. | Coal | 1 | |
| 17. | Clay shale | 100 | |
| 18. | Sandstone | 25 | |
| 19. | Clay shale | 25 | |
| 20. | Coal (Grady coal?) | | 8 |
| | Total thickness (approximate) | 1500 | |

A section across the group along a line from Adair through Chelsea and Oologah to Pawhuska is as follows:

| | | FEET. |
|---|---|---|
| 1. | Coal (Maybery coal?) | 2 |
| 2. | Clay shale | 100 |
| 3. | Limestone (Oologah limestone[1]) | 50 |
| 4. | Arenaceous clay shale and a little interstratified shaly sandstone | 200 |
| 5. | Gray limestone | 15 |
| 6. | Clay shale | 5 |
| 7. | Coal | 1¼ |
| 8. | Clay shale and sandstone | 50 |
| 9. | Limestone | 2 |
| 10. | Clay shale | 50 |
| 11. | Coal | 1½ |
| 12. | Clay shale and a little sandstone | 150 |
| 13. | Sandstone. | 25 |
| 14. | Clay shale | 15 |
| 15. | Coal (Grady coal?) | 1½ |
| | Total thickness (approximate) | 650 |

These three sections show the Cavaniol group to have the following northward variations: A regular decrease in the thickness of the group and in the relative proportion of sandstones; a gradual increase in the limestones, and a very little variation in the coals. The most marked stratigraphic feature introduced in the northern part of this group is the limestone beds.

Bed 5 of the Muscogee–Cushing section is apparently the Oologah limestone, since it has about the same stratigraphic position and shows the decrease of limestone common to the southward development of the beds. At and in the vicinity of Oologah this limestone is massive, hard, gray, rather unevenly textured, and in places contains gray chert nodules. On weathering, the limestone breaks into irregular-shaped pieces. This bed forms an east-facing escarpment fifty to one hundred feet high along the west side of Verdigris river valley east of Oologah. The limestone bed next in importance to the Oologah limestone is Bed 5 of the Adair-Pawhuska section. This limestone is beautifully exposed in bluffs along the east bank of Verdigris river, quarter of a mile below the McClellan ford east of Talala. At that place it contains no chert nodules, but in other lithologic characteristics it closely resembles the Oologah limestone.

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[1] This bed has been called the Oologah limestone because it is finely exposed in Oologah, along Four Mile creek at the west edge of Oologah, and in an escarpment some three miles to the east of that place.

*Poteau Group.*—Dr. J. P. Smith was the first to introduce the name Poteau in connection with strata included in this group.[1] It is probable that the Poteau mountain beds do not extend so high as the base of the Permian, but the name "Poteau group" will be applied to the group of beds between the Cavaniol group and the base of the Permian, as outlined in this paper. The dividing line used to separate the Poteau group from the Permian is merely an arbitrary one, and is, in the main, based on the fossils found at different localities. The beds of the Poteau group lie in small isolated areas and in a long belt-like area. The isolated areas are the upper parts of Poteau, Sugar Loaf, Cavaniol, Sans Bois, Tucker Knob and McChar mountains. The long belt-like area lies on the west side of the Cavaniol group throughout the field and has an average width of fifteen to twenty miles. The beds of this area are tilted to the northwest, where they lie against the western limit of the folded region of the Choctaw coal field, but further to the north the beds dip gently to the westward or a little north of westward. Throughout this belt the outcropping hard rock beds form east and southeast facing escarpments.

The Mayberry coal bed was not definitely located in either the Sugar Loaf or the Poteau mountains, but as these mountains do not appear to be situated in quite such deep synclines as the Cavaniol or the Sans Bois mountains the coal must be at a somewhat higher elevation. All four of these mountains are nearly the same in elevation—between twenty-five hundred and three thousand feet. From fifteen hundred to two thousand feet of the upper part of the Cavaniol and Sans Bois mountains belong to the Poteau group and twelve hundred to fifteen hundred feet of the tops of Sugar Loaf and Poteau mountains belong to this group. The group northwest of McAlester is about two thousand feet thick, but probably the top beds represent somewhat higher horizons than the top beds of the above-named mountains, since the same strata decrease in thickness to the westward and especially to the northward. This group, in the main, consists of arenaceous gray clay shales and massive sandstone beds, but in the northern region limestone beds are included in the group. The sandstone beds of this group are somewhat more massive than they are in the Cavaniol group, as is shown in Plate VIII. In the southeastern region nearly all the sandstones are massive, but southwest of Enterprise they are frequently ripple-marked and thin-bedded. Three miles south of South Canadian, sandstones form a prominent escarpment about one hundred feet high. This sandstone is composed of strata that are usually massive, but sometimes flaggy, so that beautiful smooth flags of varying thickness are common. Five or six miles farther to the west, the dark-gray clay shale overlying this bed contains some black carbonaceous fossiliferous limestone nodules. The shales along Salt creek five miles east of Calvin are light gray, very arenaceous, and carry some thin shaly layers of calcareous sandstone that are quite fossiliferous. The sandstone beds, so prominent a feature of this group in the southeast and southern region, gradually grow less prominent to the northward, but as far north as McDermitt they are the prevailing strata. A section across this group in the vicinity of Sapulpa is as follows:

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[1] *Jour. Geol.*, Vol. ii, pp. 194-196, and *Proc. Amer. Phil. Soc.*. Vol. xxxv, No. 152, p. 17.

| | FEET. |
|---|---|
| 1. Massive and slightly friable sandstones and a little interbedded clays and shales | 400 |
| 2. Clay shale | 100 |
| 3. Massive, rather friable sandstones | 200 |
| 4. Gray clay shale, calcareous in places, and containing two feet of limestone about one hundred and fifty feet from the base of the bed | 100 |

A section across this group west of Oologah shows the following sequence of strata:

| | FEET. |
|---|---|
| 1. Sandstones interbedded throughout with arenaceous clay shale | 200 |
| 2. Fossiliferous shaly limestone | 3 |
| 3. Clay shales and shaly sandstone | 50 |
| 4. Hard, massive, gray limestone | 25 |

| | FEET. |
|---|---|
| 5. Clay shale | 25 |
| 6. Arenaceous limestone | 5 |
| 7. Sandstone | 5 |
| 8. Clay shale containing calcareous nodules and some fossils | 25 |
| 9. Gray clay shale, blackened in places by carbonaceous matter often calcareous and occasionally containing thin shaly sandstone strata | 300 |
| Total thickness (approximate) | 650 |

Bed 4 of the above section forms the bed-rock of Bird creek about twelve miles from Skiatook along the Skiatook-Pawhuska road. From that point to the eastward it gradually rises until it forms bluffs on either side of the creek and farther eastward forms an east-facing escarpment.

This escarpment was seen about due west of Oologah and two to three miles west of the Osage-Cherokee Nation boundary line. The limestone bed is very massive, gray in color, unevenly textured, rather highly crystalline and contains little ferruginous masses scattered throughout most of the bed.

*Origin of the Sediments of the Coal Measures.*—Throughout the Coal Measures the thickness of the sediments gradually decreases northward and westward. The most rapid decrease is toward the north, and the lower beds decrease more rapidly than the higher ones. The Lower Coal Measures decrease from a thickness of about seventeen thousand feet in the southern part of the field to a thickness of five hundred to six hundred feet in the northern part. The Upper Coal Measures across the same field decrease from about seventy-five hundred to twelve hundred feet.

The Permian beds, so far as they were studied, show very little, if any, decrease in thickness toward the north. This continuous northward thinning of the beds in the central and northern part of the field is shown in Pl. VIII. The relative proportion in the amount of shales and limestones to sandstones and conglomerates gradually increases westward and especially northward. Because of these conditions the sediments are considered to have come from a land area lying to the southeast.

## PERMIAN.

The Permian area studied lies along the western part of the field and extends into it twenty to forty miles. Only about fifteen hundred feet of Permian sediments are included in the area studied. The base of the Permian deposits, as it is defined in the present paper, begins with the first appearance of Permian species, and not with the disappearance of the Coal Measures fauna, for that usually predominates even to the highest beds studied. The strata of the Permian beds consist of massive sandstones, clay shales, conglomerates and limestones. The clay shales are mostly gray and arenaceous, but toward the top they grade through blue to reddish and red shales and marls. The lower two hundred to one thousand feet is composed of alternating clay shale and sandstone beds in about the proportion of one hundred feet of shale to ten of sandstone. These beds are overlain by two hundred and fifty to five hundred feet of sandstones and conglomerates, and these in turn are overlain by bluish and red clay shales and marls which are interstratified with occasional thin sandstones and limestones. Four generalized sections, at widely separated localities, were made across these Permian beds. The first section extends in a northwest direction from Calvin to a point west of Wewoka near the western boundary line of the Seminole Nation. This section will be referred to as the Calvin-Wewoka section. The other three sections, with their localities, are shown in Pl. VIII.

The following table gives the generalized stratigraphy of these four sections:

| | | FEET. |
|---|---|---|
| Calvin-Wewoka Section..... | Red and blue clay shales and marls interstratified with thin sandstone and very rare limestone beds..... | 250+ |
| | Conglomerate and sandstone.................... | 250 |
| | Gray and blue clay shales interstratified with thin sandstone.............. | 600 |
| | ? Massive yellowish weathering friable sandstone ......... | 400 |

| | | |
|---|---|---|
| Swimmer-Arlington Section. | Red and blue clay shales and marls interstratified with thin sandstone and scarcer limestone beds......... | 250+ |
| | Sandstone and conglomerate | 500 |
| | Gray arenaceous clay shale beds alternating with sandstone beds in about the proportion of ten of shale to one of sandstone | 500 |
| Muscogee-Cushing Section.. | Red and blue clay shales and marls interstratified with thin sandstone beds and more rarely thin limestone beds............. | 250+ |
| | Alternating blue and gray clay shales and sandstones | 200 |
| | Sandstone and a little clay shale.................. | 500 |
| | Gray clay shales and a few thin sandstone beds..... | 100 |
| Adair-Pawhuska Section.... | Blue and red clay shales and marls alternating with thin sandstone and a few thin limestone beds. .... | 500+ |
| | Sandstone and a little clay shale................. | 500 |
| | Alternating beds of gray clay shale and thin sandstones................. | 200 |

In general terms, the section farthest to the south, or the Calvin-Wewoka section, shows two thick sandstone groups of beds with an intervening and an overlying clay shale. The other three sections show one principal group of sandstone beds overlain and underlain by clay shales. It may be possible, however, that the lower sandstone group of the Calvin-Wewoka section belongs to the Poteau group, as seems to be the case judging from lithological evidence. If this be true, there are three generalized groups running through the entire area. The following descriptions of local developments and their general connections will give a better idea of the stratigraphy and lithology.

About five miles northwest of Calvin, along Sandy creek, the strata consist of massive, friable, yellowish sandstones interstratified with gray and yellowish argillaceous compact sand. About a mile farther west, along the Calvin-Wewoka road, there are some sandstone beds exposed which are practically like the above, but are highly fossiliferous and apparently belong either to the Upper Coal Measures, or the Lower Permian. These sandstones are so friable, thick and extensive that the country for fifteen miles or more to the northwest of Calvin is covered by deep loose sand from the disintegration of the rock. Railway cuts three to four miles northwest of Holdenville show the strata at that place to be principally gray arenaceous clays with occasional reddish bands and streaks which carry numerous yellowish, ferruginous, calcareous clay nodules. There is some lenticular interbedded sandstone which is hard and has a clear quartzitic appearance. Similar clay shales and thin interstratified sandstone beds, aggregating a thickness of six hundred feet or more, are the outcropping strata for several miles on either side of Holdenville. It seems probable that this group is the base of the Permian and is the stratigraphic equivalent of about five hundred feet of similar strata outcropping both east and west of McDermitt. Farther to the north it thins quite rapidly or is replaced by sandstone beds until west of Kelleyville and northwest of Skiatook it is but one hundred to two hundred feet thick and contains no red clays. At the top of this group, along the Calvin-Wewoka section, there is a limestone from three to four feet thick. This limestone outcrops about two miles southwest of Wewoka, where it shows a weathered surface of gray and yellowish color, is very friable, and in places is quite arenaceous. About a mile farther west this limestone is overlain by a conglomerate and sandstone bed aggregating two hundred and fifty feet or more in thickness. The larger part of this bed at this locality is conglomerate, composed of rather angular light-colored chert pebbles two to three millimetres in diameter, imbedded in a sand matrix. Occasional well-rounded quartz pebbles, about five millimetres in diameter, also occur in the conglomerate. This conglomerate has the same lithologic characteristics of the conglomerate beds that extend from northern to central Texas through the Cisco division of the Coal Measures of Texas.[1] The outcrop of this conglomerate and sandstone bed forms a belt ten miles wide that extends nearly north and south through the centre of the Seminole Nation. Farther northward the conglomerate gradually disappears and the beds thicken by addition of other sandstone beds until it is apparently five hundred feet thick and outcrops in a belt about twenty miles wide. This belt lies twelve miles east of Arlington, two miles west of Kelleyville, and about eight or ten miles east of Pawhuska.

The sandstones of this belt are so friable that the country is covered by loose sand derived from the disintegrated rock. About fourteen miles east of Arlington the group contains a bed of light-gray sandy clay shale, seventy-five or one hundred feet thick, which contains some limonite nodules and one thin stratum of rich hematite. There are also two strata of limestone, each one or two feet thick, which occur near the base and top of the shales respectively.

Proceeding upward and westward across this sandstone and conglomerate group of beds from about a mile west of Kelleyville to about eight miles west of that place, the strata are found to be mainly sandstones, which are massive, rather ferruginous, friable and weather into rough irregular shapes. The rapid disintegration of the rock covers the ground with deep loose sand. About nine miles west of Kelleyville the sandstone is slightly shaly in places and some red sandy clays are interstratified with the sandstone beds. The dip of these beds is about fifty feet per mile to the westward, or a little north of westward. The thin interbedded shales and clays and alternating harder sandstone beds allow only very slight escarpments to be formed. On top of these sandstones there is about one hundred feet of gray sandy clay shale and some interstratified shaly sandstone. Over the outcrop of this shale there is not much loose sand and the bed is marked by little prairies. The dip of the strata here is about twenty to twenty-five feet per mile to the westward. Ten to eleven miles west of Kelleyville the rocks are massive cross-bedded sandstones; in these the bedding planes are curved surfaces separating their lenticular and wedge-shaped layers. It is interstratified with a little bluish argillaceous sand, red clays and gray argillaceous sandy shale. For the next five or six miles to the westward the strata lie practically horizontal, then farther west to the top of the sandstone group, which is about two miles west of Polecat creek, sixteen miles east of Cushing, the strata apparently dip about twenty-five feet per mile. The top of this group outcrops along the bed of Bird creek, one mile west of Pawhuska. On either side of the creek, beds of gray and bluish clay shales and some thin sandstone beds overlie the main sandstone group, so that it does not form the chief outcrops until a point about ten miles southeast of Pawhuska is reached.

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[1] *Geol. Surv. Texas*, Fourth An. Rep., 1892, pp. 372, 445; *Geol. Surv. Texas*, Second An. Rep., 1890, pp. 362, 495, 509, and Pl. xvi.

From Pawhuska the rocks of this group outcrop southeastward along the Skiatook-Pawhuska road for about fifteen miles. The principal variation across this Adair-Pawhuska section is a slight increase of argillaceous strata. A three-foot bed of brownish weathering arenaceous limestone occurs about one and a half miles east of the road crossing Birch creek. From Birch creek westward the dip of the strata appears to be twenty-five to thirty feet per mile to the westward, while for five or six miles to the east the strata are almost horizontal.

The next higher group of Permian beds consists of bluish and red clay shales and marls, interstratified at rather wide intervals with thin cross-bedded sandstones and occasional thin limestones. The following local developments will give the usual characteristics. The lower part of this group, as seen eight to nine miles west-southwest from Wewoka, consists of sandy clay shales, bluish and reddish colored, and massive sandstones that have edges and parts of the rock broken into thin shaly wedge-shaped, cross-bedded strata. The sandstone is either light grayish or reddish-colored. The gray sandstone is coarse textured. Farther westward and higher geologically the sandstones decrease in quantity and most of the strata are red clay shales.

Two and a half miles southeast of Econtuska there is a little white, nodular, arenaceous limestone interstratified with yellowish marls. The strata at Bellmont and between that place and Arlington are mainly red arenaceous, calcareous clays interstratified with occasional red sandstones which are usually rather massive, but often broken into shaly and flaggy parts by cross-bedding planes. Some of the sandstone has a light gray-color. There are also rare beds of arenaceous and even quite pure fossiliferous limestone which varies in color from white and gray to red and almost invariably weathers to rough nodular fragments. One of these beds outcrops one mile west of Arlington. Five or six miles east of Arlington there is a one to three-foot bed of hard crystalline red limestone which is overlain by a thin clay bed, and this in turn by sandstone conglomerate similar to that west of Wewoka.

The limestone that outcrops one mile west of Arlington is probably the same as the one that occurs sixteen miles east of Cushing and two miles west of Pawhuska. Dr. J. P. Smith called the limestone bed that outcrops from two to three miles west of Pawhuska, the Pawhuska limestone.[1]

The limestone bed that outcrops about sixteen miles east of Cushing is from four to six feet thick, gray, bedded in rough, thin layers, and contains *Fusulina* and crinoids. The strata here lie almost horizontal, and the same bed outcrops ten miles east of Cushing along the Kelleyville-Cushing road. About five miles east of Cushing higher beds of massive friable cross-bedded sandstone, red clay, and arenaceous limestone outcrop. Some of the limestone is quite pure, but usually it occurs in nodular form in beds one-half to one foot thick. In the vicinity of Cushing clay shales and marls are the principal strata. Six miles north-northwest from Cushing along the south or east bank of the Cimarron river there is a bluff about fifty feet high showing massive and shaly sandstones of light gray or yellowish and reddish color, sometimes cross-bedded. A little rough concretionary limestone occurs at the top of the bed. The twin peaks from ten to eleven miles north of Cushing are composed of red clays capped by concretionary limestone. Some of the limestone contains chert. The Pawhuska limestone outcrops about twelve miles north of Cushing along branches of Salt creek. The bed at this locality is about five feet thick, gray in color, hard, rough surfaced, unevenly textured and rich in two species of *Fusulina*.

The following section was compiled from outcrops of strata found five to ten miles south of Pawnee.

| | | FEET. |
|---|---|---|
| 1. | Red clays | at top. |
| 2. | Limestone | 1½ |
| 3. | Red, bluish and gray clays | 150 |
| 4. | Limestone (Pawnee limestone)[2] | 2 |
| 5. | Principally gray clay shales | 100 |
| 6. | Pawhuska limestone | 5 |

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[1] *Jour. Geol.*, Vol. ii, p. 199.

[2] Stratum 4 appears to be the same as the bed of limestone outcropping on the east side of the courthouse grounds at Pawnee, and for convenience it will be called the Pawnee limestone.

The Pawnee limestone outcrop on the east side of the courthouse grounds at Pawnee consists of three to four feet of hard evenly textured, tough, bluish gray limestone underlain by five to six feet of yellowish blue marls. Both the limestone and marls are rich in fossils. The Pawhuska limestone bed which outcrops in the bed of a creek half a mile northeast of Pawnee at an elevation of about one hundred feet below the Pawnee limestone, is, at this place, about five feet thick; the lower three feet is hard and massive, while the upper part of the bed is friable. *Fusulinæ* are very abundant in this bed.

Four miles south of Ralston in the banks of Coal creek there is a three to five-inch bed of coal which appears to be below the Pawnee limestone. The following section was compiled from exposures of an escarpment facing the Arkansas river valley at a point about two miles southeast of Ralston.

| | | FEET. |
|---|---|---|
| 1. | Light gray and yellowish weathering sandstone | 15 |
| 2. | Gray clay shale | 4 |
| 3. | Nodular gray limestone (Pawnee limestone ?). | 3 |
| 4. | Red clays and light gray shaly sandstones | 100 |
| 5. | Pawhuska (?) limestone | 5 |

The Pawhuska limestone outcrops along the Gray Horse-Pawhuska road at every creek crossing for seven to eight miles from Gray Horse, and also about five miles southwest of Pawhuska. At the latter place it is about ten feet thick, unevenly textured, gray in color, and underlain by yellowish and bluish clays. A section of the strata in the vicinity of Pawhuska is about as follows:

| | | FEET. |
|---|---|---|
| 1. | Blue and red clays | at top. |
| 2. | Pawhuska limestone | 10 |
| 3. | Clay shale | 50 |
| 4. | Sandstone | 50 |
| 5. | Clay shale | 150 |
| 6. | Sandstones | at base. |

This limestone outcrop forms a little escarpment facing east and running north about two miles west of Pawhuska, while the first sandstone bed below the limestone cap the buttes and escarpments around the village.

## GENERAL CLASSIFICATION OF ROCKS OF THE INDIAN TERRITORY.[1]

| SYSTEM. | SERIES. | GROUP. | CORRELATIONS. | BEDS. | MAXIMUM THICKNESS IN FEET. |
|---|---|---|---|---|---|
| Carboniferous | Permian. | | Albany division, Texas.<br>Neosho and Chase formations, Kansas. | Shales, sandstones, conglomerates and limestones. | 1,500 |
| | Coal Measures | Poteau. | Wabaunsee and Cottonwood formations, Kansas<br>Cisco division, Texas. | Massive and shaly sandstones and shales. | 2,000 |
| | | Cavaniol. | Missouri formation, Kansas. | Shales, sandstones and coals | 5,500 |
| | | Lower Coal M. | Strawn, Milsap and Canyon divisions, Texas | Shales, sandstones. | 17,000 |
| | Lower Carboniferous. | Boston. | St. Louis. | Limestones, shales and sandstones. | 200 |
| | | | | Batesville sandstone. | 25 |
| | | Osage. | Osage. | Fayetteville shale. | 50 |
| | | | | Boone chert and limestone. | 500 |
| | | | | Eureka shale. | 50 |
| | | Kinderhook. | | Wanting. | |
| Devonian. | Devonian. | | | Wanting. | |
| Silurian. | Upper Silurian | | Niagara, New York.<br>St. Clair Marble, Arkansas. | Marble and saccharoidal sandstone. | 75+ |
| | Lower Silurian | | | Saccharoidal sandstone, chert and dolomitic sandstones and limestones. | 200+ |

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[1] Since this paper was put in type Mr. Stuart Weller has definitely correlated the Batesville sandstone of these tables with the Aux Vases sandstone of Illinois. His results show that the hitherto tentative correlations of these Arkansas and Indian Territory rocks require more careful paleontologic study.—*Trans N. Y. Acad. Sci.*, xvi, 251–282.

## PART II.

### PALEONTOLOGY.

The fossils collected from various localities over the field are listed in locality groups, and arranged in their stratigraphic order. All the species listed here and the originals figured are deposited in the geological museum of Stanford University.

### LOWER CARBONIFEROUS.

*Upper Boone Limestone* (Burlington-Keokuk).—Collections of fossils from the upper Boone limestone were made at three different localities. At the north side of West monntain, three miles southeast of Westville, the following fauna was found :

1. *Productus scabriculus* ? Martin.
2. *Productus cherokeeensis* n. sp. Drake.
3. *Productus* (*Marginifera*) *adairensis* n. sp. Drake.
4. *Productus ovatus* Hall.
5. *Athyris* (*Seminula*) *subquadrata* Hall.
6. *Rhynchonella grosvenori* White.
7. *Spirifer keokuk* Hall.
8. *Eumetria vera* Hall.
9. *Rhynchonella mutata* ? White.
10. *Discina* sp.?
11. *Archimedes* sp.?

Seven miles east of Adair the upper Boone limestone contains the following fauna :

1. *Productus* (*Marginifera*) *adairensis* n. sp. Drake.
2. *Productus ovatus* Hall.
3. *Productus longispinus* ? Sowerby.
4. *Productus* sp.?
5. *Derbya kaskaskiensis* McChesney.
6. *Spirifer keokuk* Hall.
7. *Athyris* (*Seminula*) *subquadrata* Hall.
8. *Orthothetes crenistria* Phillips.
9. *Myalina* sp.?
10. *Archimedes* sp.?

The following fossils were collected from outcrops of the upper Boone limestone found along Ballard's creek one mile west of Echo:

1. *Orthothetes crenistria* Phillips.
2. *Productus cestriensis* Worthen.
3. *Orthis swallovi* Hall.
4. *Eumetria vera* Hall.
5. *Athyris* sp.?
6. *Archimedes* sp.?
7. *Phillipsia* sp.?

*Fayetteville Shale* (Warsaw).—No fossils were collected from the shale itself, but the limestone bed that occurs near the centre of the shale bed is very fossiliferous in places. One and a half miles south of Vinita *Productus cestriensis* Worthen is a very common fossil in this limestone. East of Chouteau on either side of Grand River valley, opposite Ned Adair's ferry, the following fauna was collected from this limestone:

1. *Productus ovatus* Hall.
2. *Productus cherokeeensis* n. sp. Drake.
3. *Productus alternatus* N. and P.
4. *Productus* sp.?
5. *Productella* sp.?
6. *Athyris* (*Seminula*) *subquadrata* Hall.
7. *Athyris* sp.?
8. *Spirifer keokuk* Hall.
9. *Spirifer trigonalis* Martin.
10. *Rhynchonella* (*Camarophoria*) *cooperensis* Shumard.
11. *Chonetes planumbona* M. and W.
12. *Pentremites godoni* de France.
13. *Pleurotomaria taggerti* Meek.
14. *Pleurotomaria* sp.?
15. *Platyceras* sp.?
16. *Edmondia burlingtonensis* White and Whitfield.
17. *Edmondia ellipsis* White and Whitfield.

*Boston Group* (St. Louis–Chester).—A very good representative fauna of this group was collected at four different localities. Most of the fossils came from the Archimedes and Pentremital horizons. The following fauna was found in this group east of Grand river, opposite Wagoner, about one and a half miles northeast of the mouth of Fourteen Mile creek.

1. *Productus ovatus* Hall.
2. *Productus cestriensis* Worthen.
3. *Productella* sp.?
4. *Spirifer* sp.?
5. *Terebratula bovidens* Morton.
6. *Athyris* (*Seminula*) *subquadrata* Hall.
7. *Athyris* sp.?
8. *Camarophoria wortheni* Hall.
9. *Eumetria verneuilana* Hall.
10. *Eumetria vera* Hall.
11. *Aviculopecten simplex* ? Dawson.
12. *Posidonomya fracta*? Meek.
13. *Edmondia* sp.?
14. *Pentremites godoni* de France.
15. *Archimedes communis* Ulrich.
16. *Archimedes swallovana* Hall.
17. *Archimedes terebreformis* Ulrich.
18. *Archimedes* sp.?
19. *Zaphrentis spinulifera* Hall.
20. *Phillipsia* sp.?

The following fauna was collected from this group five miles east of Adair.

1. *Productus* (*Marginifera*) *adairensis* n. sp. Drake.
2. *Productus cherokeeensis* n. sp. Drake.
3. *Productus cestriensis* ? Worthen.
4. *Productus pertenuis* ? Meek.
5. *Productella* sp.?
6. *Chonetes loganensis* ? Hall.
7. *Orthis dubia* Hall.
8. *Orthothetes crenistria* Phillips.
9. *Spiriferina kentuckensis* Shumard.
10. *Rhynchonella grosvenori* White.
11. *Eumetria verneuilana* Hall.
12. *Spirifer keokuk* Hall.
13. *Athyris* (*Seminula*) *subquadrata* Hall.
14. *Phillipsia scitula* M. and W.

Seven or eight miles southeast of Big Cabin the following collection was made:

1. *Productus cherokeeensis* n. sp. Drake.
2. *Productella* sp.?
3. *Athyris* (*Seminula*) *subquadrata* Hall.
4. *Spiriferina kentuckensis* Shumard.
5. *Rhynchonella grosvenori* White.
6. *Eumetria vera* Hall.
7. *Chonetes* sp.?
8. *Archimedes* sp.?
9. *Zaphrentis* sp.

The Boston group contains the following fauna one and a half miles south of Vinita:

1. *Productus cherokeeensis* n. sp. Drake.
2. *Productus cora* ? d'Orbigny.
3. *Athyris* (*Seminula*) *subquadrata* Hall.
4. *Chonetes planumbona* ? M. and W.
5. *Spiriferina kentuckensis* Shumard.
6. *Spirifer keokuk* Hall.
7. *Straparollus lens* ? Hall.
8. *Zaphrentis lanceolata* ? Worthen.
9. *Archimedes proutanus* M. and W.
10. *Michelinia eugeneæ* White.
11. *Orthoceras* sp.?
12. *Bellerophon* sp.?
13. *Pleurotomaria* sp.?

## COAL MEASURES.

### LOWER COAL MEASURES.

The Lower Coal Measures are very poor in fossils, and collections of any special value were made at only three different localities:

Along the limestone bed and ridge two and a half miles south of Ponola and Wilburton.

1. *Productus longispinus* ? Sowerby.
2. *Productus cora* ? d'Orbigny.
3. *Derbya crassa* ? M. and W.
4. *Rhynchonella illinoisensis* Worthen.

5. *Athyris* sp.?
6. *Spiriferina* ? *kentuckensis* Shumard.
7. *Retzia* ?
8. *Spirifer* sp.?
9. *Spirifer rockymontanus* Marcou.
10. *Septopora* ?
11. *Playtyceras* sp.?

One mile south of Muscogee the following fossils were found in shaly and friable limestones and arenaceous clay shales:

1. *Productus pertenuis* ? Meek.
2. *Productus splendens* N. and H.
3. *Productus longispinus* Sowerby.
4. *Spirifer lineatus* Martin.
5. *Spirifer rockymontanus* Marcou.
6. *Spirifer* sp.?
7. *Derbya crassa* M. and P.
8. *Discina convexa* Shumard.
9. *Athyris* (*Seminula*) *subtilita* Hall.
10. *Septopora biserialis* Swallow.
11. *Zaphrentis* sp.?

Four miles north of Vinita, where the M. K. & T. railway crosses a brook, the following fauna was collected from some black shale:

1. *Productus pertenuis* ? Meek.
2. *Spirifer cameratus* Morton.
3. *Athyris* (*Seminula*) *subtilita* Hall.
4. *Derbya crassa* Meek and Hayden.
5. *Chonetes* sp.?
6. *Belleropon* sp.?

### UPPER COAL MEASURES.

*Cavaniol Group.*—This group is represented in the collection of fossils from five different localities as follows:

The following fossils were found in a ferruginous sandstone one hundred and fifty feet above the Grady coal and four miles northwest of Hackett, Ark.

1. *Derbya crassa* M. and H.
2. *Nuculana bellistriata* Stevens.
3. *Bellerophon carbonarius* Cox.
4. *Aviculopecten occidentalis* Shumard.

One and a half miles west of Starvilla along a little branch some shaly argillaceous limestone contains great numbers of *Productus pertenuis*? Meek, and *Discina nitida* Phillips occurs rarely. In some ferruginous sandstone, six miles southwest of Salisaw on the east side of Big Salisaw creek, the following fauna was collected:

1. *Productus cora* d'Orbigny.
2. *Terebratula bovidens* Morton.
3. *Athyris* (*Seminula*) *subtilita* Hall.
4. *Spirifer rockymontanus* Marcou.
5. *Retzia* (*Hustedia*) *mormoni* Marcou.
6. *Derbya crassa* M. and H.
7. *Aviculopecten occidentalis* Shumard.

The following fauna was collected from the Oologah limestone in the western part of the town of that name:

1. *Productus semireticulatus* Martin.
2. *Athyris* (*Seminula*) *subtilita* Hall.
3. *Chonetes* sp.?
4. *Syringopora* sp.?

The following fossils were found in the limestone bed that outcrops along Verdigris river a quarter of a mile below the McClellan ford, which is about four miles east of Talala. This limestone belongs about two hundred feet below the Oologah limestone:

1. *Productus punctatus* Martin.
2. *Productus semireticulatus* Martin.
3. *Productus* (*Marginifera*) *splendens* N. and P.
4. *Productus pertenuis*? Meek.
5. *Spirifer cameratus* Morton.
6. *Spirifer lineatus* Martin.
7. *Spiriferina kentuckensis* Shumard.
8. *Athyris* (*Seminula*) *subtilita* Hall.
9. *Chonetes mesoloba* N. and P.
10. *Chonetes* sp.?
11. *Fusulina cylindrica* Fischer.

*Poteau Group Fauna.*—Collections of fossils were made at four different localities in this group. The shales immediately overlying the Mayberry coal bed at the coal mines, four miles northwest of Poteau, contain the following fauna:

1. *Discina nitida* Phillips.
2. *Aviculopecten rectilaterarius* Cox.
3. *Aviculopecten dubertianus* Dawson.
4. *Nuculana bellistriata* Stevens.
5. *Nucula ventricosa* Hall.
6. *Bellerophon carbonarius* Cox.
7. *Gastrioceras globulosum* ? Meek and Worthen.

Six miles southwest of South Canadian some limestone nodules included in a clay shale bed contain the following fossils:

1. *Nucula ventricosa* Hall.
2. *Pleurotomaria sphærulata* Conrad.
3. *Bellerophon crassus* Meek and Worthen.

Five or six miles northwest of Calvin, the following fauna occurs in friable sandstones:

1. *Productus semireticulatus* Martin.
2. *Productus pertenuis* ? Meek.
3. *Strophalosia* ? *spondyliformis* White and St. John.
4. *Schizodus wheeleri* Swallow.
5. *Nuculana bellistriata* Stevens.
6. *Murchisonia* sp. ?
7. *Pinna peracuta* Shumard.
8. *Aviculopecten catactus* ? Meek.
9. *Gastrioceras globulosum* Meek and Worthen.

Ten miles south of Okmulgee, about one hundred and fifty feet above the base of the Poteau group, the following fossils were found in sandstone:

1. *Aviculopecten occidentalis* Shumard.
2. *Solenopsis solenoides* Geinitz.
3. *Pleurophorus angulatus* Meek and Worthen.

The following fossils were collected west of Oologah, about two miles west of the Cherokee-Osage Nation boundary line:

1. *Productus splendens* N. and P.
2. *Spirifer cameratus* Morton.
3. *Spirifer lineatus* Martin.
4. *Athyris* (*Seminula*) *subtilita* Hall.
5. *Spiriferena kentuckensis* Shumard.

6. *Meekella striatocostata* Cox.
7. *Temnocheilus forbesianus* McChesney.
8. *Chonetes* sp. ?

Near the top of the group, at a place about ten miles northwest of Skiatook, the following fauna was found in sandstone strata:

1. *Chonetes verneuilana* N. and P.
2. *Chonetes laevis* Keyes.
3. *Productus* sp. ?
4. *Sanguinolites* sp. ?

### PERMIAN FAUNA.

Good collections of fossils were made at three different places from beds that are classed as the lowest Permian. The first two lists given below afford the evidence that has been used to draw the line between the Permian and the Coal Measures. These two collections of fossils come from widely separated localities and apparently from the same stratigraphic position.

Five miles east of McDermitt along the McDermitt-Chelsea road the following fauna was found in beds of sandstone.

1. *Productus semireticulatus* Martin.
2. *Productus nebrascensis* Owen.
3. *Productus auriculatus* Swallow.
4. *Orthis* sp. ?
5. *Derbya crassa* Meek and Hayden.
6. *Nuculana bellistriata* Stevens.
7. *Pinna peracuta* Shumard.
8. *Aviculopecten occidentalis* Shumard.
9. *Aviculopecten* sp. ?
10. *Myalina swallovi* McChesney.
11. *Edmondia aspenwallensis* Meek.
12. *Edmondia reflexa* Meek.
13. *Schizodus wheeleri* Swallow.
14. *Schizodus insignis* nov. sp. Drake.
15. *Macrodon obsoletus* Meek.
16. *Macrodon carbonarius* Cox.
17. *Bakevellia parva* ? M. and H.
18. *Murchisonia marcouiana*.
19. *Gervilia ohioensis* Herrick.

20. *Pleurophorus angulatus* Meek and Worthen.
21. *Pleurophorus* sp.?
22. *Pleurotomaria* sp.?
23. *Pseudomonotis hawni* Meek and Hayden.

Four miles west of Sapulpa and about one-half of a mile north of the Sapulpa-Kelleyville road the following fauna was collected.

1. *Productus cora*? d'Orbigny.
2. *Derbya crassa* Meek and Hayden.
3. *Chonetes verneuilana* Norwood and Pratten.
4. *Chonetes lævis* Keyes.
5. *Myalina swallovi* McChesney.
6. *Nucula bellistriata* Stevens.
7. *Edmondia nebrascensis* Geinitz.
8. *Dentalium meekianum* Geinitz.
9. *Solenopsis solenoides* Geinitz.
10. *Yoldia subscitula* Meek and Hayden.
11. *Schizodus wheeleri* Swallow.
12. *Pseudomonotis hawni*? Meek and Hayden.
13. *Pleurophorus angulatus* Meek and Worthen.
14. *Pleurophorus* sp.?
15. *Pleurophorus* sp.?
16. *Pleurotomaria sphærulata*? Conrad.
17. *Murchisoma* sp.?
18. *Bellerophon carbonarius* Cox.

Three or four miles west of McDermitt, and about one mile west and northwest of the Pigler place, there are some highly fossiliferous sandstones. These beds are three hundred or four hundred feet above the base of the beds containing the fossils of the above two lists. Fossils were collected from two different sandstone beds in these higher horizons four miles west of McDermitt. The lower sandstone bed contains the following fossils:

1. *Productus nebrascensis* Owen.
2. *Productus auriculatus* Swallow.
3. *Pinna peracuta*? Shumard.
4. *Myalina swallovi* McChesney.
5. *Aviculopecten occidentalis* Shumard.
6. *Pleurotomaria* sp.?

The upper fossiliferous sandstone bed lies about fifty to seventy-five feet higher and contains the following fauna:

1. *Productus semireticulatus* Martin.
2. *Productus nebrascensis* Owen.
3. *Productus pertenuis* Meek.
4. *Productus auriculatus* Swallow.
5. *Derbya crassa* Meek and Hayden.
6. *Athyris* sp.?
7. *Orthis resupinoides*? Cox.
8. *Edmondia gibbosa* Swallow.
9. *Pinna peracuta* Shumard.
10. *Myalina swallovi* McChesney.
11. *Myalina recurvirostris*? Meek and Worthen.
12. *Myalina subquadrata* Shumard.
13. *Schizodus wheeleri* Swallow.
14. *Schizodus curtus*? Meek and Worthen.
15. *Bakevellia parva*? Meek and Hayden.
16. *Dentalium meekianum* Geinitz.
17. *Monopteria gibbosa* Meek and Worthen.
18. *Aviculopecten occidentalis* Shumard.
19. *Nucula bellistriata* Stevens.
20. *Pseudomonotis hawni* Meek and Hayden.
21. *Gervillia ohioensis* Herrick.
22. *Loxonema cerithiforme*? Meek and Worthen.
23. *Avicula* sp.?
24. *Avicula* sp.
25. *Pleurophorus* sp.
26. *Sanguinolites*?

The Seminole sandstone and conglomerate beds that run northward through the Territory are, as a rule, barren of fossils, and no collections of importance were made in them.

*Pawnee and Pawhuska Beds.*—Collections of fossils from these beds were made at ten different localities. These fossils were collected from strata that apparently extend from the base of the Pawhuska limestone to a horizon three hundred or four hundred feet above that limestone. The first five lists of fossils come from strata that appear to belong to the Pawhuska limestone. One to four miles southwest of Arlington the following fossils were found in a limestone bed.

1. *Productus* (*Marginifera*) *splendens* Norwood and Pratten.
2. *Spirifer cameratus* Morton.
3. *Chonetes verneuilana* Norwood and Pratten.
4. *Allorisma subcuneatum* Meek and Hayden.
5. *Pinna peracuta* ? Shumard.

The following fauna was found in what appears to be the Pawhuska limestone, along branches of Salt Creek twelve miles north of Cushing.

1. *Spirifer cameratus* Morton.
2. *Spirifer planoconvexus* Shumard.
3. *Athyris* sp. ?
4. *Schizodus wheeleri* Swallow.
5. *Zaphrentis* sp.
6. *Fusulina cylindrica* Fischer.
7. *Fusulina gracilis* ? Meek.

About ten to fifteen feet above this limestone, at a place eleven miles south of Pawnee, the following fossils were collected :

1. *Productus cora* d'Orbigny.
2. *Chonetes granulifera* Owen.
3. *Spirifer cameratus* Morton.
4. *Athyris sultilita* Hall.
5. *Myalina subquadrata* Shumard.
6. *Bellerophon percarinatus* Conrad.

The following fossils were found in the limestone bed outcropping in the bed of the creek at the road crossing one-half mile northeast of Pawnee courthouse.

1. *Productus* (*Marginifera*) *splendens* Norwood and Pratten.
2. *Chonetes granulifera* Owen.
3. *Chonetes lævis* Keyes.
4. *Rhynchonella* (*Pugnax*) *uta* Marcou.
5. *Spirifer cameratus* Morton.
6. *Athyris* (*Seminula*) *subtilita* Hall.
7. *Fusulina cylindrica* Fischer.

The following fauna was found in the Pawhuska limestone at a place about four and one-half miles southwest of Pawhuska.

1. *Productus semireticulatus* Martin.

2. *Productus cora* d'Orbigny.
3. *Athyris* (*Seminula*) *subtilita* Hall.
4. *Spirifer cameratus* Morton.
5. *Spirifer planoconvexus* Shumard.
6. *Chonetes* sp. ?
7. *Lophophyllum proliferum* Hall.
8. *Pleurotomaria illinoisensis* Worthen.

The following fossils were collected from a friable limestone bed that occurs about one hundred and fifty feet above the Pawhuska limestone, at a place five miles east of Cushing.

1. *Productus pertenuis* Meek.
2. *Derbya crassa* Meek and Hayden.
3. *Chonetes granulifera* Owen.
4. *Spirifer cameratus* Morton.
5. *Aviculopecten occidentalis* Shumard.
6. *Myalina* sp. ?
7. *Rhombopora lepidodendroides* ? Meek.

Ten miles north of Cushing the following fauna was collected from some limestone strata capping Twin hills.

1. *Spirifer cameratus* Morton.
2. *Productus* (*Marginifera*) *splendens* N. and P.
3. *Chonetes granulifera* Owen.
4. *Athyris* (*Seminula*) *subtilita* Hall.
5. *Syntrielasma hemiplicatum* Hall.
6. *Fusulina cylindrica* Fischer.

On the east side of the courthouse grounds at Pawnee there is an outcrop of four feet of limestone, and four feet of fossiliferous calcareous gray clays. Fossils collected from this bed are as follows:

1. *Productus semireticulatus* Martin.
2. *Productus cora* d'Orbigny.

. *Productus pertenuis* Meek.

4. *Productus nebrascensis* Owen.
5. *Productus* (*Marginifera*) *splendens* N. and P.
6. *Spirifer cameratus* Morton.
7. *Spirifer planoconvexus* Shumard.
8. *Derbya crassa* Meek and Hayden.
9. *Meekella striatocostata* Cox.

10. *Rhynchonella* (*Pugnax*) *uta* Marcou.
11. *Chonetes granulifera* Owen.
12. *Orthis pecosi* Marcou.
13. *Athyris* (*Seminula*) *subtilita* Hall.
14. *Aviculopecten occidentalis* Shumard.
15. *Euomphalus rugosus* Hall.
16. *Fusulina cylindrica* Fischer.
17. *Rhombopora lepidodendroides* Meek.
18. *Zeacrinus* sp.?

The following list of fossils shows the fauna that was found about two miles southeast of Ralston, in a bed of limestone, and marls that appear to be the same as that in Pawnee.

1. *Productus semireticulatus* Martin.
2. *Productus nebrascensis* Owen.
3. *Productus* (*Marginifera*) *splendens*? N. and P.
4. *Rhynchonella* (*Pugnax*) *uta* Marcou.
5. *Derbya crassa* Meek and Hayden.
6. *Spirifer cameratus* Morton.
7. *Spirifer* (*Ambocœlia*) *planoconvexus* Shumard.
8. *Athyris* (*Seminula*) *subtilita* Hall.
9. *Spiriferina kentuckensis* Shumard.
10. *Meekella striatocostata* Cox.
11. *Chonetes granulifera* Owen.
12. *Chonetes lævis* Keyes.
13. *Retzia* (*Hustedia*) *mormoni* Marcou.
14. *Orthis pecosi* Marcou.
15. *Avicuiopecten occidentalis* Shumard.
16. *Aviculopecten* sp. ?
17. *Avicula speluncaria* Geinitz (not Schlotheim).
18. *Myalina subquadrata* Shumard.
19. *Myalina perattenuata* Meek and Hayden.
20. *Astarte* sp. ?
21. *Bellerophon* sp. ?
22. *Lophophylium proliferum* Hall.
23. *Phillipsia scitula*? Meek and Worthen.

The following fauna was collected from sandstone beds that outcrop six to seven miles southwest of Pawhuska along the Pawhuska-Gray Horse road. These sandstone beds are probably one hundred and fifty feet above the Pawhuska limestone.

1. *Pinna peracuta* Shumard.
2. *Schizodus wheeleri* Swallow.
3. *Schizodus rossicus* Verneuil.
4. *Nucula bellistriata* Stevens.
5. *Aviculopecten* sp. ?
6. *Pleurophorus angulatus* Meek and Worthen.
7. *Pleurophorus* sp. ?
8. *Myalina swallovi* McChesney.
9. *Yoldia subscitula* Meek and Hayden.
10. *Pleurotomaria perhumerosa* Meek.
11. *Bellerophon* sp. ?

## DESCRIPTIONS OF SPECIES.

*Productus* (*Marginifera*) *adairensis* sp. nov. Drake. Pl. IX, Figs. 1–3.

Shell small, the largest specimen found being three-quarters of an inch in height, and seventeen-twentieths of an inch in greatest breadth, at hinge line. Beak highly arched, and projecting one-third of the entire height of the shell above the hinge line. Ears slightly extended. Surface ornamented with very fine ribs, and occasional small spines, and in the region of the beak, with a slight reticulation. The ventral valve has a distinct medial sinus, which begins near the beak. The outside of the shell resembles somewhat *Productus multistriatus* Meek, of the Upper Carboniferous, but has the ribs even finer, and the beak somewhat more slender than that species. The inside of the shell shows the characters

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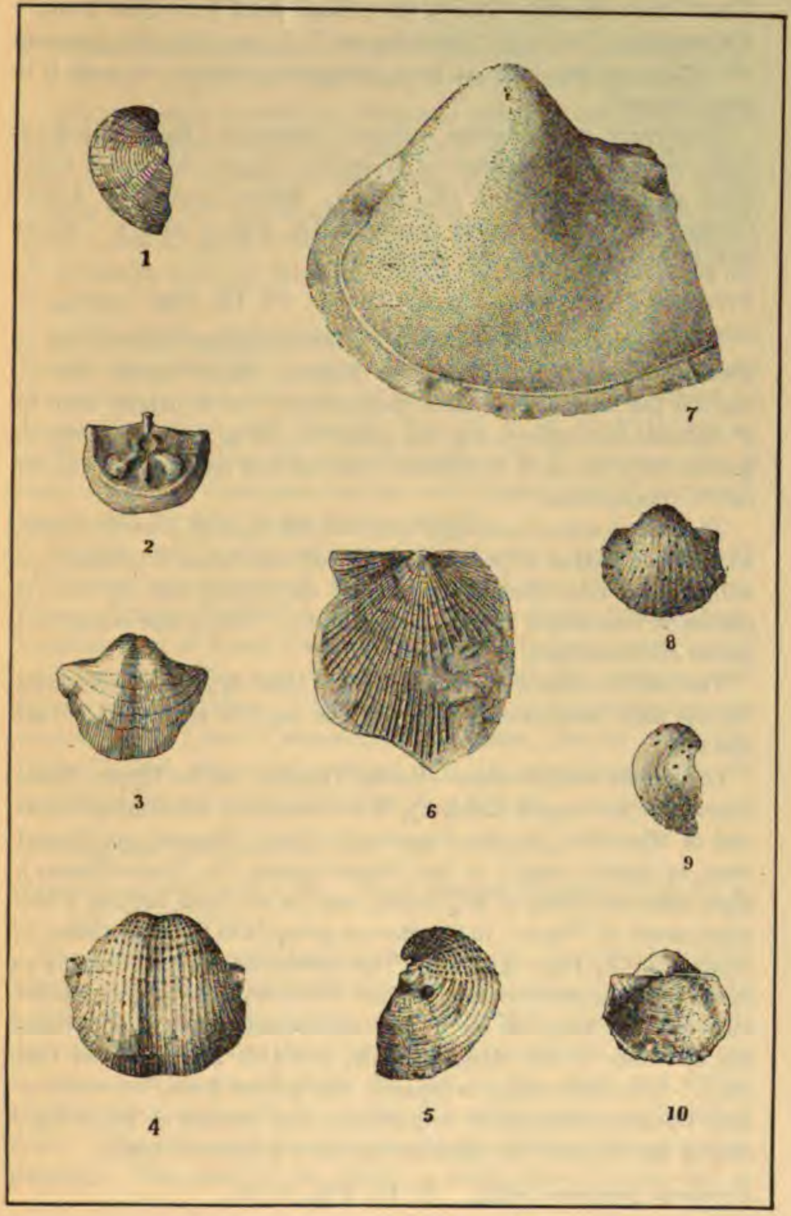
*Plate IX.*

| | PAGE. |
|---|---|
| FIGS. 1, 2 and 3.—*Productus adairensis* nov. sp. Drake. Fig. 2, from Boone limestone, seven miles east of Adair. Figs. 1 and 3, from Boston group, five miles southeast of Adair | 403 |
| FIGS. 4 and 5.—*Productus cherokeeensis* nov. sp. Drake. Boston group, five miles southeast of Adair | 403 |
| FIG. 6.—*Aviculopecten rectilaterarius* Cox. Upper Coal Measures, Poteau group, four miles northwest of Poteau | 403 |
| FIG. 7.—*Schizodus insignis* nov. sp. Drake. Permian, five miles east of McDermitt | 403 |
| FIGS. 8, 9 and 10.—*Productus pertenuis* Meek. Lower Carboniferous, St. Louis-Chester, five miles southeast of Adair | 403 |

*Plate IX.*



assigned by Waagen to his genus Marginifera, although Hall and Clarke have recently shown, in "Nat. History of New York," *Palæontology*, Vol. viii, "Brachiopoda," p. 331, that the genus is not valid, and can have at most subgeneric value. As such it is here retained.

*Occurrence and Horizon.*—Boone limestone (Burlington-Keokuk), three miles southeast of Westville; Boone limestone, seven miles east of Adair, Pl. IX, Fig. 2; Boston group (St. Louis-Chester), five miles east of Adair, Pl. IX, Figs. 1 and 3. About fifteen specimens collected, altogether.

*Productus cherokeeensis* nov. sp. Drake. Pl. IX, Figs. 4 and 5.

This species resembles closely *P. semireticulatus* Martin, but is always smaller, more compressed laterally, more highly arched, and has the mesial sinus more pronounced. It is nearest akin to *P. inflatus* McChesney, but the umbo is not so prominent, nor so greatly incurved as in *P. inflatus;* also the ribs seem a little coarser on *P. cherokeeensis.*

The dorsal valve is strongly concave, the ventral is very convex, with strong medial sinus. The surface of both valves is ornamented with distinct ribs, often dichotomous; the region near the beak is distinctly reticulated by the growth lines. There are occasional spines on the surface.

The ears are somewhat more extended than on *P. semireticulatus*, but the total proportional width of the shell is less than on that species.

*Occurrence and Horizon.*—Rather common in the Upper Boone limestone (Burlington-Keokuk), West mountain, three miles southeast of Westville; in the Fayetteville shale (Warsaw), on Grand river, at Adair's ferry; in the Boston group (St. Louis-Chester), eight miles southeast of Big Cabin, and in the same horizon a half miles south of Vinita; in the Boston group, five miles southeast of Adair, Pl. IX, Figs. 4 and 5. The species is confined entirely to the Lower Carboniferous in Indian Territory, and a very similar form has been found in the Fayetteville shale (Warsaw) of Arkansas, and also in the Marshall shale, probably St. Louis, of that State. It is worth while to separate this species from *P. semireticulatus* from its stratigraphic importance, and because of the unlikeness of the two and the difference of their associated faunas.

*Productus pertenuis* Meek. Pl. IX, Figs. 8–10.

*Productus pertenuis* Meek. *Final Report U. S. Geol. Survey Nebraska*, p. 164, Pl. I, Fig. 14, Pl. VIII, Fig. 9.

*Productus cancrini* Geinitz. *Carbon und Dyas in Nebraska*, p. 54, Pl. IV, Fig. 6 (not Murchison, Verneuil and Keyserling).

The specimens referred to *Productus pertenuis* are rather larger than those figured by Meek, and have somewhat stronger radial ribs. But the thinness of the valves, the great convexity of the ventral valve, the lack of a medial sinus, and the disposition of the small spines all agree with the figures and descriptions of Meek's *P. pertenuis*, and the form referred by Geinitz to *P. cancrini* M. V. K.

Adults of the shell average about three-fifths of an inch wide and the same in height; convexity of the valve for a shell of these dimensions is nine-twentieths of an inch. The shell referred by Meek, *Geol. Expl. 40th Parallel*, Vol. iv, p. 78, Pl. VIII, Fig. 4, to *P. longispinus* Sowerby, probably belongs to *P. pertenuis*, for it lacks the medial sinus, and has the other characters of *P. pertenuis*, except that the beak is not quite so slender.

*Horizon and Locality*.—Lower Coal Measures, four miles north of Vinita; one mile south of Muscogee: Upper Coal Measures, Cavaniol group, McClellan ford on Verdigris river; Poteau group, six miles west of South Canadian; Permian division, upper bed of sandstone four miles west of McDermitt; Pawhuska sandstone, five miles west of Cushing. The same or a nearly related species also occurs in the Lower Carboniferous limestone, Boston group (St. Louis-Chester), five miles southeast of Adair; a specimen from this locality is figured on Pl. XII, Figs. 8, 9 and 10.

*Aviculopecten rectilaterarius* Cox. Pl. IX, Fig. 6.

*Avicula rectalaterarea* Cox. *Geol. Survey Kentucky*, Vol. iii, p. 571, Pl. ix, Fig. 2.

The shell is somewhat semicircular in outline, the greatest length being about equal to the greatest width. The hinge line is straight and nearly equal to the greatest width. The beak is small, rounded, does not project above the hinge line. The rounded anterior ear is rather sharply set off from the rest of the shell, and differs slightly from it in having the radial ribs rather coarser and further apart. The left valve has the base of the anterior ear somewhat notched. The posterior ear, which is longer than the anterior, is not distinctly set off from the rest of the shell, but differs from it in ornamentation, so as to be well marked.

The surface is marked by distinct radial ribs, somewhat narrower than the interspaces. These ribs are often dichotomous, and also increase by intercalation. Near the beak the surface is faintly ornamented with distinct concentric striæ of growth, which grow stronger towards the posterior margin. The ears are ornamented just as the rest of the shell, except that the ribs are somewhat coarser on both anterior and posterior ears.

*A. rectilaterarius* resembles very closely *A. papyraceus* Sowerby of the European Coal Measures, and indeed a more perfect suite of specimens may show their identity, for many of the species that accompany *A. papyraceus* in Europe have already been found in America.

*Horizon and Locality.*—Upper Coal Measures, Poteau group, in the shales overlying the Mayberry coal, at the mines four miles northwest of Poteau, Indian Territory.

*Schizodus insignis* sp. nov. Drake. Pl. IX, Fig. 7.

This species, one of the largest of the genus Schizodus, is represented in the collection only by a cast, so that the generic reference is not beyond doubt. The shell is large, being two and a half inches in length and two inches in height. Convexity of the valve is eleven-twentieths of an inch. The beak is rather high and pointed, rising two-fifths of an inch above the hinge line. The anterior margin is rounded, the posterior is broken off. The anterior and posterior adductor impressions are quite large and distinct. The cast is smooth, so nothing is known of the sculpture of the surface. The only species with which *Schizodus insignis* may be compared is *Schizodus* (*Leptodomus*) *magnus* Worthen, *Geol. Surv. Ill.*, Vol. viii, p. 107, Pl. XVIII, Fig. 2, of the Lower Carboniferous, Chester horizon; but *S. magnus* differs from *S. insignis* in the elongation of the anterior part of the valve, also in the sharp high ridge that runs from behind the beak obliquely to the rear of the shell. Otherwise there is considerable similarity, and the two species may very well belong to the same genus.

*Occurrence and Horizon.*—In hard sandstone of the Permian horizon, five miles east of McDermitt, Indian Territory; only a single specimen was found.

## PART III.

## ECONOMIC GEOLOGY.

The coals of the Indian Territory are at present its most important geologic product. The part of this paper treating of economic geology must therefore be devoted principally to coal.

### COALS OF THE CHOCTAW FIELD.

*Grady Bed.*—The outcrops and workable areas of the Grady coal bed are confined to three continuous narrow belts. One belt encircles the Backbone anticline, one the Bokoshe-Milton anticline, and the other lies at the south bases of the Poteau, Cavaniol and Sans Bois mountains. The bed around the Backbone anticline enters the Indian Territory on the north side of the axis east of Pocola, and runs about S. 80° W. At the Territory line the bed is almost horizontal, or dips slightly to the north, as shown in Section No. 5, which was made across the Backbone anticline southeast of Pocola.

One mile west of Pocola the coal bed dips 15° to 20° to the north; the coal is three feet and seven inches thick, and has one thin parting of shaly coal nineteen inches from the bottom of the bed. Fire clay underlies the coal and arenaceous clay shale overlies it. The increased dip of the coal bed to the west from the Territory line is probably due to the decrease in the throw of the fault along the north side of Backbone mountain, so that the strata enter into the anticlinal fold. It is possible that the Poteau river west and north of Pocola runs along a gentle anticline; if so, the coal bed is deflected down that stream on either side. The dip of the rock west of Pocola, however, does not make this probable. At any rate, a few miles west of Poteau river along the general direction of the coal outcrop, the dip of the rocks shows conclusively that the bed is continued westward from that place. The coal bed has been opened near the Kansas City, Pittsburgh and Gulf Railway at several places on either side of Buck creek prairie and east of Poteau river. This coal is being worked to a very limited extent a half mile east of Poteau river and a half mile south of James fork of Poteau river; the coal at that place is twenty-eight inches thick, dips 10° S. and is overlain and underlain by black clay shale. The bed increases in thickness towards the west, so that a few miles west of Poteau river it is four feet thick. The Bokoshe-Milton anticlinal fold brings this coal bed up so that its outcrop swings around that anticline. This outcrop has been prospected along most of its length at intervals of one-fourth to one-half mile.

West of Ward the coal is four to five feet thick and dips 25°. Southwest of Ward, at the Coleman place, a well passes through six feet and two inches of coal, including a parting of very shaly coal one and a half inches thick, two feet from the top. One-half mile further south the coal is said to be five and a half feet thick. The dip of the coal bed increases slightly toward the south for a mile or two. South of Bokoshe it is about four feet thick and dips 25°. One and a half miles east of Milton the coal is three feet eight inches thick. A half mile south of Milton, at the Ward Brothers' coal bank, the coal bed is parted by twelve to eighteen inches of shale; the upper stratum of coal is twenty-six inches and the lower forty-four inches thick. Gray clay shale underlies and overlies the coal. A half mile further west the coal bed is parted by five inches of shale, the upper stratum of coal is twenty-two inches thick and the lower four feet two inches thick; the dip is 23°. A half mile still further west the upper stratum of coal is twenty-eight inches thick, the shale parting three inches; only about four feet of the lower stratum of coal was seen, and the bed is a little thicker than that; dip of bed 22° S.

Farther to the west the coal slightly decreases in thickness, while eastward and northward on the north side of the loop it decreases rather rapidly, until it is about eighteen inches thick west of Bokoshe, and about fourteen inches thick northwest of Bokoshe.

This coal bed dips southward under the Sugar Loaf, Poteau, Cavaniol and Sans Bois mountains and comes to the surface again on the south side of those mountains, as shown in Secs. 1, 2, 3 and 4. The coal bed along this south line of outcrops is often split by partings varying in thickness from a few inches to fifty feet, and several thin strata of coal are common near the main bed. The following section, from a railway cut one and a quarter miles south of Heavener, shows the nature of this coal group at that and a number of other places:

| | FEET. | INCHES. |
|---|---|---|
| Shale | 2 | |
| Coal | | 8 |
| Shale | 15 | |
| Shaly coal | 1 | |
| Shale and streaks of coal | 5 | |

| | FEET. | INCHES. |
|---|---|---|
| Coal | | 6 |
| Carbonaceous shale | 1 | 6 |
| Coal | | 2 |
| Carbonaceous shale | 2 | |
| Coal | | 4 |
| Carbonaceous shale | 1 | 6 |
| Coal | | 1½ |
| Carbonaceous shale | 1 | 6 |
| Shale | 15 | |
| Sandstone | 25 | |
| Shale | 12 | |
| Sandstone | 5 | |
| Shale | 2 | |
| Coal | | 1 |
| Carbonaceous shale | | 11 |
| Coal | | 1½ |
| Carbonaceous shale | | 6 |
| Coal | | 2 |
| Shale | | 3 |
| Coal | | 1 |
| Shale | | 2 |
| Coal | 1 | |
| Shale | 4 | |
| Coal | 2 | |

Three miles east of this section the coal is two feet six inches thick. One and a half miles southwest of Heavener it is twenty-eight inches thick. Three miles northwest of Heavener the coal has been mined considerably and is said to be about four feet thick.

This coal has been mined quite extensively where it is touched and crossed by the St. Louis and San Francisco Railway. At the most easterly point touched by the railway, a place once called Pocohontas, the coal lies in two beds separated by about fifty feet of shale; the upper coal bed is thirty-seven inches thick and the lower one forty-four inches, and the bed dips about 45°.

At Wilburton preparations for extensive coal mining were being made in 1896. The coal occurs in two beds separated by about fifty feet of shale. The upper bed is about four feet thick; the lower one was not accessible in 1896, but the superintendent of the mine reported it a little over four feet thick. The coal is apparently of uniform good quality. This bed is now being worked extensively at Cherry Vale, about three or four miles northeast of Krebs, where it averages about three feet four inches thick, is uniformly good and dips about 12° N. From this mine the coal outcrop runs but little farther west before it swings to the south and then turns east some twenty miles, when it again swings to the south and back west again, thus forming an S-shaped outcrop at this place. The eastward loop of the S outlines a small synclinal basin called by Dr. H. M. Chance the Grady basin.[1] Coal is extensively mined in this basin at Hartshorne. The coal is composed of one four-foot bed, which is worked, and other higher, thinner beds, not worked. The synclinal fold, forming the basin, is a gentle one so that the dip of the rocks on its sides are only 4° to 5°. Chance[2] says: "The maximum depth of the Grady coal bed in this basin is about 600 feet; but over three fourths of the basin the bed can be reached at depths less than four hundred and fifty feet, and over one-half of the basin the depth will probably not exceed three hundred feet. The basin is about six miles long by three or four wide and contains over 11,000 acres of the Grady bed. Throughout this area the coal is not always of workable thickness; but over a large portion of it the bed will range from three and a half to five feet thick, yielding an average of four feet of clear coal."

This coal outcrop west of Hartshorne is so broken by faults and tilted by very irregular folds that it is not easily located. The three-foot bed of coal that outcrops in Brushy creek, about five miles west of Hartshorne, appears to be the Grady bed. Here it shows a fault of four or five feet and dips to the southwest 5° to 6°. About two miles further west, that is, seven miles west of Hartshorne and one-fourth of a mile northeast of the Brunton place, this coal outcrops again and is three feet eight inches thick, but with two partings of shaly coal in it. One three to four-inch parting is within three inches of the base, and ten inches from the base of the bed there is a shaly parting from one to two inches thick.

*McAlester Coal Bed.*—The outcrop of the McAlester coal bed is greater than that of the Grady bed, since it does not lie so deep and does not require such excessive foldings to bring it up or such profound erosion to reach it. The outcrop is shown on Pl. I with the exception of areas near the Canadian and Arkansas rivers and around the base of Sugar Loaf and Poteau mountains. These latter places were not sufficiently examined to locate the line of outcrop. This coal bed varies in thickness from about one and a half to about four feet. The thickest part of the bed is in the southwest part of the field or about McAlester, Krebs and Alderson. It appears to thin gradually eastward and northward. In the northern part of the field it is almost regularly eighteen inches thick. This bed is now, and has been for some time, extensively mined at Alderson, Krebs and McAlester. The coal bed at Alderson and Krebs is about three feet six inches thick. One-half mile southwest of McAlester, at D. Edwards & Son's mine, the coal is four feet thick. The dip of the coal bed from Alderson to McAlester varies from about 6° to 25°; the gentler dips are at and near Krebs. The outcrop northwest, north and east of McAlester for some distance lies along a faulted area, so that the coal bed occurs in blocks dipping irregularly and usually at very steep angles. In this faulted area no place has yet been worked extensively and profitably. Farther to the east the coal has not been found sufficiently thick to pay for working. Southeast of Red Oak it is two feet thick and dips 20°. North of Red Oak, in Brazil Creek valley, it is about two feet thick and dips very gently.

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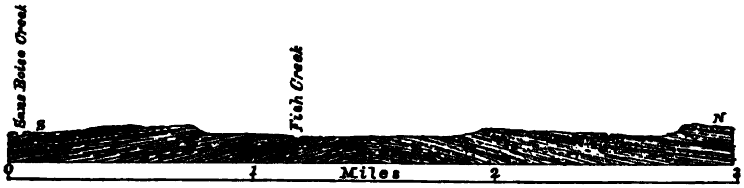
[1] *Trans. Am. Inst. Min. Eng.*, Vol. xviii, p. 654.

[2] *Ibid.*, p. 659.

At and near Fanshaw the coal is thirty inches thick, dips about 25° and was once considerably but unprofitably mined. About five or six miles east of Fanshaw, in Big Caston creek, the coal is twenty-eight inches thick and dips 35°. The coal once mined at the west edge of Poteau seems to be this bed; it is said to be about two feet thick at that place.

About two and a half miles southwest of Cameron this coal is eighteen inches thick and dips to the southward 2° to 3°. It is occasionally mined to a limited extent by stripping. At this place there is a shale parting in the bed six inches from the base of the coal. In wells on the farm of Mr. Henry Choate, about four to four and a half miles west of Brazil, this coal is reported to be from two to two and a half feet thick. About three miles south of Milton, in Owl creek, near its mouth, this coal bed is eighteen inches thick; some six miles further west in Owl creek, one-fourth mile east of Haney Smith's, the coal is only thirteen inches thick; the dip of the bed about 20°.

Southeast of Sans Bois, along Mountain Fork of Sans Bois creek, the coal is a little more than a foot thick at the places where it was seen. About three miles west or north of west from Sans Bois, on a branch of Fish creek, in Mr. Scott's pasture, this coal is seventeen inches thick; dips 4° to 5° N. 10° W.



Sec. 14. Across the Sans Bois anticline, four miles west of Sans Bois.

The above cut shows the structure four miles west of Sans Bois. About seven miles west of Sans Bois, in Beaver creek, the coal is fifteen inches thick. About four and a half miles east-northeast from Sans Bois and one-fourth of a mile east of Mr. Ben Noel's place, this coal is eighteen to twenty inches thick; four miles north-northeast of Sans Bois, in the banks of Sans Bois creek, it is eighteen to nineteen inches thick. About three miles north of Sans Bois, along Cedar creek, the coal is eighteen to twenty inches thick, and dips, 5° to 10°. Two miles west of Iron Bridge this coal is twenty-six to twenty-seven inches thick and quite uniform throughout. About four miles west-southwest from Cashier the coal is eighteen inches thick. Two miles west of Stigler, in Cane prairie, the coal is twenty-eight inches thick and of excellent quality. On Rock branch, one mile west of Whitefield, the coal is twenty-seven to twenty-eight inches thick. The Canadian river, north and northeast of Whitefield, appears to run along an anticlinal fold. If this is the case, the east end of the coal outcrop, west of Whitefield, follows down the east side of Canadian river valley and joins the coal outcrop running northward from east of Whitefield; the westward extension of the coal outcrop, west of Whitefield, ascends Canadian river valley probably nearly opposite Brooken before crossing that river and running back east and northeast by Starvilla, as seems to be the case.

*Mayberry Coal Bed.*—This coal was not located in the Sugar Loaf or Poteau mountains, but it is doubtless represented there. The coal in the east end of San Bois mountains, at some three hundred to four hundred feet above the base of the mountains, and that on the north side of the mountains near the west end, probably belong to this bed. Sans Bois mountains were not studied closely enough to outline the coal outcrop. The final disappearance of the Mayberry bed, under the westward dipping strata, is shown by the coal outcrop located west and southwest of Enterprise. This coal bed is being mined quite extensively in the east end of Cavaniol mountain by the Kavanaugh Coal, Coke and Railway Company. The bed at this place averages about three feet eight inches in thickness and dips slightly to the southwest. On the opposite side of the cañon, from where it is worked and about one hundred and forty feet lower, there is what appears to be another bed of coal. This lower bed contains some shale, as is shown by the following section :

| | FEET. | INCHES. |
|---|---|---|
| Coal | | 5 |
| Clay shale | | 1½ |
| Coal | 1 | |
| Shale | | 9 |
| Coal | 2 | 6 |

The layers of shale found in this lower bed and its difference in elevation indicate a different horizon from the one that is being worked, but it seems possible, from the cursory examination made, that they may be the same bed. If they are not the same bed, the lower or more shaly bed is probably a local deposit, for but one coal bed of importance was found at other places over the field at the horizon of the Mayberry coal.

On the north side of Cavaniol mountain, at the original place of discovery of the Mayberry coal, the beds show the following sequence :

| | FEET. | INCHES. |
|---|---|---|
| Coal | 1 | 5 |
| Clay shale | | 3 |
| Coal | | 8 |
| Clay shale | | 3 |
| Coal | 1 | 10 |

This coal is a short distance above the fourth thick sandstone bed of the Cavaniol mountains.

A coal bed eighteen inches thick outcrops in the northeast end of

Sans Bois mountains one mile south of Henry Blaylock's house and three hundred or four hundred feet up on the mountain side. It is quite uniformly good except one and a half inches of shaly coal three or four inches from the bottom of the stratum. The coal is overlain by sandstone and underlain by clay. This coal was traced one-half mile or more around the hillside and was about the same wherever it was seen. From its position it seems to belong to the Mayberry coal bed. The coal near the head of Ash creek and near the west end of the Sans Bois mountains is said to be about eighteen inches thick. The bed that appears to represent the Mayberry coal, along the western border of the folded area, is from eighteen to twenty-four inches thick and of a good quality. About four miles northeast of Reams, at the west end of Sans Bois prairie, this coal is twenty-four inches thick. The bed is very much fractured at this point, which is on the axis of the Sans Bois anticline. About eight miles south of Enterprise and one and a half miles southwest of Russelville, along the head waters of Old Town creek, the coal is twenty-nine inches thick, including a thin parting of shaly coal eight inches from the base and another seven inches from the top. On the southwest side of McChar mountain, along the head waters of Long Town creek, the coal is nineteen inches thick. One-half mile above the mouth of Old House creek, it is twenty-one inches thick. The coal outcrops on Haytubya creek one-half mile from its mouth and about six miles west-southwest from Enterprise. At this place it is twenty-three inches thick and good throughout, but closely fractured by lines a half to one inch apart; dip of bed 2° to 3°. About four and a half miles west-southwest from Enterprise, the coal has been worked to some extent by stripping. At that place it is twenty-two inches thick and uniform throughout. One and a half miles north of Enterprise, the coal is twenty-six inches thick and is worked for local demands by stripping.

## Coals of the Cherokee and Creek Nations.

In those parts of the Indian Territory lying within the Cherokee and Creek Nations the coal beds were not traced in detail, and were seen usually only at widely separated intervals, and cannot therefore be definitely outlined in this discussion. However, the structure of the area is quite regular, so that the general extent and connections of the various coals can be fairly well outlined.

*Grady Coal.*—The lowest coals found through the Cherokee and Creek Nations will be discussed under this heading, though it is doubtful whether they represent the northern continuation of the Grady bed, or whether they all belong to the same bed. The northern and eastern limit of the Cavaniol group, as outlined on the accompanying map, shows the approximate outcrop of this coal bed. The following local developments were seen: About one mile east of Little Salisaw creek, and one-fourth of a mile south of the Kansas City, Pittsburgh & Gulf Railroad, this bed of coal outcrops and has been worked to some extent by stripping. The coal is said to be one and a half feet thick and of good quality. The strata overlying the bed dip 15° to 20° north-northwest. About three miles southwest of Salisaw Station the same coal outcrops along Coal creek. It is one to one and a half feet thick, and has been mined by stripping. This coal was, in the summer of 1896, being used by blacksmiths in Salisaw, who pronounce it an excellent one for their work. The mines were all filled with water at the time the writer visited the place. Along the south side of Spaniard creek, at the Weber's Falls-Muscogee road crossing, the coal bed is ten to twelve inches thick and is mined for local demands. The bed dips north-northwest about 12°. Going from this point toward Muscogee, the synclinal basin is crossed at right angles and the coal outcrop is again seen about four miles southeast of Muscogee. The eastern end of this synclinal fold lies near Braggs, where the bed has been worked a little. It outcrops along branches about two miles south of Braggs, and is four to six inches thick. It is said to underlie Braggs at an average depth of about thirty feet and is six inches thick. Five miles west of Muscogee and one mile south of the Arkansas river, this coal has been worked a little. At that place the coal is eight to twelve inches thick. It outcrops again four miles north-northwest of Adair, along the side of an east-facing escarpment. Where it was seen (the Ross coal bank), the coal is seventeen inches thick, underlies a gray shale and is apparently rather high in ash and sulphur.

This coal outcrops along Log Cabin creek, about three miles west of Welch, where it is said to be about two feet thick, and is mined for local demands.

*McAlester Coal Bed.*—This coal outcrop is approximately located on the map from near Starvilla to Dirty or Elk creek, northeast of Checotah. One and a half miles northwest of Starvilla the coal is about two feet thick. It is mined to some extent along the Thomas fork of Elk creek, at a place about six miles east of Checotah, where it is about fourteen inches thick. Along Elk or Dirty creek, about four miles east of Checotah, the coal is eighteen to twenty-four inches thick. From Starvilla to Elk creek, and doubtless much farther, a five to six-inch seam of coal occurs regularly fifty to seventy-five feet above the McAlester bed. These beds in the Choctaw coal field are separated by about one hundred feet of gray clay shale.

The McAlester coal outcrops six or seven miles southwest of Muscogee, where it is about one foot thick and is worked for local demands.

Another outcrop was seen four or five miles west of Chelsea, where it was worked at several places for local demands. At the Robinson bank it is eighteen inches thick, and of uniform quality throughout. At the McFadden coal bank the same qualities are shown.

About a hundred feet above this bed and four miles farther west, a coal bed fifteen inches thick outcrops. It is also worked somewhat for local use by stripping. This bed is probably not represented south of the Canadian river, but the outcrops along Coal creek, twelve miles east-northeast from Okmulgee, and those five to six miles southwest of Chelsea, are probably the same. On Coal creek the coal is about fifteen inches thick and quite uniformly good. The bed dips 1° to 3°, is overlain by carbonaceous clay shale, and underlain by fire clay. Southwest of Chelsea the coal is about ten inches thick and of very good quality.

*Mayberry Coal Bed.*—The coals occurring at the top of the Cavaniol group, and that probably represent the northern extension of the Mayberry bed, were seen as follows:

The upper bed outcrops along Coal creek, twelve miles south of Okmulgee, where it is parted by from four to eight inches of shale and shaly coal. The upper stratum of coal is fourteen inches thick and the lower one is from fourteen to sixteen inches thick. Both strata are apparently good, but iron pyrites is rather common in places through the coal. In general appearance this coal is almost identical with that occurring four or five miles west of Chelsea, and the chemical analyses show them to have the same general properties. The next outcrop of this coal bed was seen along Coal creek, about six miles east of Sapulpa. At that place it is from twenty-two to twenty-four inches thick where it was examined, and has three to four shale partings, which are from a quarter to half an inch thick. Gray clay shale overlies the coal. The Mayberry coal bed was seen next at a place three miles northwest of Oologah, where it is two feet thick and rather uniform throughout. It is mined rather extensively by stripping for shipping to distant markets as well as for local demands. This same bed outcrops along Little Verdigris or Caney river at Mustgroves crossing, where it is about one and a half feet thick, according to report.

These local developments show that the best coals of the Cherokee and Creek Nations are only about two feet thick, but that they extend through the entire length of the Nations.

*Coal Analyses.*—At each locality where coals were collected for analyses, samples were selected to represent the average coal of that particular place; but as no guide save the appearance of the coal could be used in sampling, the analyses will necessarily not show the quality of the coal as well as may be desired. They will, however, show fairly well the characteristics of the coals and their adaptability to various uses. In the table of coal analyses the coal beds are placed in the same relative position that they occupy in the field, so that the Mayberry coals are first or at the top, the McAlester coals in the centre, and the Grady coals at the bottom. In each group the analyses begin with coals in the west and northwest part of the field and proceed eastward and southeastward. The groups thus proceed from higher to lower coals; the analyses of each group, and the groups also to some extent, run from a region of less to a region of greater folding and crushing. This arrangement clearly shows the decrease in the bituminous nature of the coals toward the region of greater dynamic movements. The coals are practically all bituminous, only that from near the mouth of James fork of Poteau river and that from near Milton being semi-bituminous. All the coals show a probability of coking, and a considerable quantity of slack coal from mines at Alderson and Krebs is now being coked. Most of the coals, however, are too high in sulphur to produce good coke for metallurgical uses. Some of the coals are objectionably high in sulphur, water, or ash, but as a whole they compare favorably with good coals from other fields.

*Coal Oil.*—During the summer of 1896, several wells were sunk, two hundred to three hundred feet deep, along Spencer creek val-

## COAL ANALYSES BY N. F. DRAKE.

| Bed. | Locality. | Thickness of Coal Beds. | Water. | Volatile Hydro-Carbons. | Fixed Carbon. | Ash. | Sulphur. | Fuel Ratio. | Color of Ash. | Coking Tests. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mayberry Bed. | Three miles northwest of Oologah, Cherokee Nation. | 1′ 0″ | 3.35 | 34.99 | 57.88 | 3.15 | 1.21 | 1.65 | Light yellow. | Fused and doubled in size. | |
| | Four miles east-northeast from Reams, Choctaw Nation. | 2′ 0″ | 1.62 | 32.92 | 55.79 | 9.65 | . . . | 1.69 | Lavender. | Fused and increased one and a half times. | Sulphur not determined. |
| | Twelve miles south of Okmulgee, Creek Nation. | 2′ 4″ | 6.31 | 30.78 | 59.92 | 2.11 | 0.87 | 1.94 | Light yellow. | Fused and increased in size one and a half times. | |
| | Six miles west-southwest of Milton, in north end of Sans Bois mountains. | 1′ 6″ | 0.95 | 31.71 | 57.75 | 9.57 | . . . | 1.82 | Brick red. | Fused and increased in size about ten times. | Sulphur not determined. |
| | Four miles northwest of Poteau, Choctaw Nation. | 3′ 8″ | 1.36 | 17.23 | 64.54 | 12.46 | 4.40 | 3.80 | Reddish brown. | Fused and increased in size about ten times. | |
| | Eight miles west of Chelsea, Cherokee Nation. | 1′ 3″ | 2.77 | 34.61 | 56.17 | 6.43 | . . . | 1.62 | Brick red. | Fused and increased in size about five times. | Sulphur not determined. |
| McAlester Bed. | Four and a half miles west of Chelsea, Cherokee Nation. | 1′ 6″ | 6.26 | 27.16 | 64.17 | 1.84 | 0.56 | 2.36 | Yellowish white. | Fused and increased in size one and a half times. | |
| | One-half mile southwest of McAlester. | 4′ 0″ | 3.33 | 29.75 | 61.78 | 4.37 | 0.75 | 2.07 | Yellowish brown. | Fused and increased one and a quarter times. | |
| | Alderson, Choctaw Nation. | 3′ 4″ | 2.35 | 32.42 | 58.47 | 4.32 | 2.42 | 1.80 | Light lavender. | Fused and increased in size one and a half times. | |
| | Three miles north-northwest of Sans Bois. | 1′ 6″ | 1.60 | 24.83 | 68.69 | 2 95 | 1.90 | 2.76 | Reddish brown. | Fused and increased in size about ten times. | |
| | One and a half mile northwest of Starvilla, Cherokee Nation. | 2′ 0″ | 1.25 | 22.49 | 62.18 | 7.88 | 6.18 | 2.77 | Brick red. | | |
| | Two miles west of Stigler, Choctaw Nation. | 2′ 4″ | 1 66 | 23.01 | 72.49 | 1.92 | 0.91 | 3.15 | Light yellow. | Fused and increased in size about ten times. | |
| | Two miles west of Iron Bridge. | 2′ 3″ | 1.21 | 19.67 | 73.46 | 3.40 | 2.25 | 3.75 | Brick red. | Fused and increased in size about ten times. | |
| Grady Bed. | Cherry Vale mine, Choctaw Nation. | 3′ 4″ | 2.54 | 30.90 | 62.37 | 3.56 | 0.60 | 2.01 | Yellowish brown. | Fused and increased in size very little. | |
| | Hartshorne. | 4′ 0″ | 2.69 | 35.65 | 54.91 | 4.12 | 2.62 | 1.54 | Reddish brown. | Fused and increased in size one and a half times. | |
| | Upper stratum of coal bed, one-half mile south of Milton. | 2′ 2″ | 1.12 | 14.23 | 77.31 | 4.04 | 3.28 | 5.43 | Lavender. | Fused and increased in size about eight times. | |
| | Lower stratum of coal bed, one-half mile south of Milton. | 4′ 2″ | 0.98 | 13.60 | 73.84 | 7.83 | 3.72 | 5.43 | Lavender. | Fused and increased in size about eight times. | |
| | One and a half mile southwest of Heavener. | 2′ 4″ | 3.67 | 19.46 | 72.83 | 3.28 | 0.74 | 3.74 | Light yellowish brown. | Fused and increased in size but very little. | |
| | Near the mouth of James fork of Poteau river, Choctaw Nation. | 2′ 4″ | 1.20 | 13.75 | 82.95 | 1.16 | 0.92 | 6.03 | Yellowish brown or nearly orange. | Fused but increased very little in size. | |

ley, four to five miles west of Chelsea. Some of the wells flow, but none of them produce very much oil. The foreman of the works informed me that the greatest flow of any one well was about a barrel per day, and that the oil was struck in a micaceous shaly sandstone. This sandstone is probably the bed that outcrops east of Chelsea, and lies between the two lower coal beds. The rock beds are practically horizontal in the area where the oil wells have been sunk, but the strata passed through, in sinking the wells, come to the surface farther eastward. The oil is probably derived from the Lower Coal Measures shale beds that outcrop along the Missouri, Kansas & Texas Railway, east of Chelsea.

*Building and Ornamental Stone.*—The sandstones, limestones, marbles and granite that occur in this field are adapted to many uses in construction work. Sandstones are very abundant, except in the Boone chert area, throughout almost the entire field. They are usually evenly textured, massive, tough, and are well adapted for ordinary building purposes. The best limestones for building purposes are confined to the Lower Carboniferous and especially to the upper Boone limestone horizon. Massive beds of tough gray evenly-textured limestone are common in the Boone limestones. The Boston group also contains some good building limestones and occasional thin beds of limestone were seen in the Permian area that are fairly good for building purposes. The outcrops of the marble beds are shown in Pl. IV. Massive beds of marble, twenty-five to thirty feet thick, outcrop at nearly every marble area shown in that plate. The thickness of the marble beds has not yet been determined, but from drill borings it appears to be one hundred and fifty feet or more. The marble is usually pink colored, but some of it is gray and a little is practically white. So far, the marble that has been quarried contains a great many fractures and rather abundant small cavities, partly or entirely filled with large calcite crystals. Further investigation may result in finding better marbles than the surface outcroppings. Some of the bed that is at present being quarried can be advantageously used for building and ornamental uses.

The granite found on Spavinaw creek is an excellent stone for building and ornamental purposes, but it is at present too far from any railway to be profitably quarried for marketing. For a more extended discussion of the various kinds of rock previous pages may be consulted.

CONTRIBUTIONS TO BIOLOGY

FROM

THE HOPKINS SEASIDE LABORATORY

OF. THE

LELAND STANFORD JR. UNIVERSITY.

XV

# Description of a Species of Fish (Mitsukurina owstoni) from Japan, the Type of a Distinct Family of Lamnoid Sharks.

BY

DAVID STARR JORDAN.

Reprinted from Proceedings of the California Academy of Sciences,
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SAN FRANCISCO, CAL.
1898.

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*(Continued on Third Page of Cover.)*

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## XVI

# The Development of Lytoceras and Phylloceras

BY
JAMES PERRIN SMITH

Reprinted from the Proceedings of the California Academy of Sciences,
3d Ser., Geol., Vol. I.

SAN FRANCISCO, CAL.
1898

# PREFATORY NOTE.

This memoir is the sixteenth of a series designed to illustrate investigations and explorations connected with the Hopkins Seaside Laboratory, an adjunct of the biological laboratories of the Leland Stanford Junior University. These investigations have been carried on by means of the assistance given by Timothy Hopkins, Esq., of Menlo Park, California. This memoir appears in the publications of the California Academy of Sciences, the present edition being a reprint.

Oliver P. Jenkins,
Charles H. Gilbert,
*Directors Hopkins Laboratory.*

Date of publication, September 20, 1898.

# THE DEVELOPMENT OF LYTOCERAS AND PHYLLOCERAS.

BY JAMES PERRIN SMITH.

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## INTRODUCTION.

*Lytoceras* and *Phylloceras* are exceedingly interesting because they are simple, unspecialized genera, long-lived, little changed, and yet with the power of giving off other variable branches. They are the two longest lived genera of ammonites, ranging from about the end of the Trias to the Upper Cretaceous, at least seven millions of years by a conservative estimate. According to most authorities these are the only groups of ammonites in the Jura that do not belong to the stock of the *Arietidæ*, and according to others they are the ancestors of even that stock through *Psiloceras*.

It is in these old, unspecialized genera that we must seek to unravel the genealogical tangle, either in the older for-

August 29, 1898.

mations, or in survivals of the old types in later times. At first sight it seems a hopeless task ever to work out the family history of the ammonites; for, as Quenstedt once remarked, a man might hope to count the stars of the heavens, or even at a venture the sands of the sea, but the species of ammonities are beyond his ken. But it is just this infinity that gives hope of success; the grading of one form into another by imperceptible steps affords an accurate check on the results of ontogenetic study. And it is quite clear, too, that a few genera furnish the key to the puzzle, since in the later formations the majority of forms were retrogressive and only a few remained simple and progressive.

Because of the interest in *Lytoceras* and *Phylloceras* as persistent types and progenitors of many genera of ammonites in the Jura and Cretaceous, this investigation was undertaken to find out their relationship with each other, and with contemporary genera.[1] If a series of species of *Lytoceras* and *Phylloceras* could be found in all the successive beds of the Jura and Cretaceous it would be comparatively easy to establish in this way a genetic series. But, as Neumayr[2] has shown, they appear sporadically in successive zones, lacking entirely in many, and not forming a genetic series even where they are known. They must, therefore, have been immigrants from some outside region, supposed by Neumayr to have been the ancient Mediterranean sea, or "Thetys" of Suess.

Since it is not possible to get a genetic series of adults, the next best thing is to take some representative species and work out its ontogeny. "The *Ammonoidea* preserve in each individual a complete record of their larval and adolescent history, the protoconch and early chambers being enveloped and protected by later stages of the shell; and by breaking off the outer chambers, the naturalist can in effect cause the shell to repeat its life history in inverse order, for each stage of growth represents some extinct ancestral genus. These genera appeared in the exact order of their minute imitations in the larval history of their descendants, and by a comparative study of larval stages with adult forms the naturalist finds the key to relationships, and is enabled to arrange genera in genetic series."[1] The method used in this investigation is that given in the paper cited above; it was first discovered by Hyatt, and afterwards used by Branco with such valuable results. By this method a series is not pieced out by selecting a number of separate individuals supposed to represent successive stages of the same species, but a number of well preserved individuals is selected, large enough to make sure of the identity of the species, and the specimens are reduced by pulling off the outer coils to any stage desired. The old way was to mount the specimens in Canada balsam on a glass slide, but this is unsatisfactory, for it allows a view in only one direction. The writer has found it much better to keep the small specimens separate in labelled tubes, and to use three different mounts in microscopic study; dry on white cardboard, to study the shape and surface markings; in a drop of water spread out so as not to distort the object, to show the septa; under water in a watch-glass over a strong condensing lense, to study the siphon, inner septa, and other organs when the cast or shell is translucent. The viscosity of water will hold the minute object in any desired position, so a fixed mount is unnecessary.

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[1] The writer has been engaged for a number of years in studying the ontogeny of various species of ammonites, representing the most important genera, in comparing ontogenetic stages with preceding forms, and thus in working out the phylogeny of the ammonites.

[2] Jahrb. K. K. Geol. Reichsanstalt, Wien, Bd. XXVIII, 1878, pp. 58-59.

## NOMENCLATURE OF STAGES OF GROWTH.

In order to correlate stages of growth of the individual with generic stages seen in the development of the race, it is necessary to have an exact scientific nomenclature. The most satisfactory is that given by Professor Hyatt in "Phylogeny of An Acquired Characteristic."[2]

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[1] Journal Geol. Vol. V, 1897, No. 5, J. P. Smith, "Comparative Study of Palæontogeny and Phylogeny," p. 517.

[2] Proc. Amer. Phil. Soc., Vol. XXXII, No. 143, pp. 391 and 397.

## Table of Ontogenetic Stages.

| *Stages.* | | *Stages.* | *Substages.* | *Comparison with Phylogeny.* | |
|---|---|---|---|---|---|
| Embryonic | (1) | Embryonic | Phylembryonic | Phylembryonic | Epacme. |
| Larval | (2) | Nepionic | Ananepionic<br>Metanepionic<br>Paranepionic | Phylonepionic | |
| Adolescent | (3) | Neanic | Ananeanic<br>Metaneanic<br>Paraneanic | Phyloneanic | |
| Adult | (4) | Ephebic | Anephebic<br>Metephebic<br>Parephebic | Phylephebic | Acme. |
| Senile | (5) | Gerontic | Anagerontic<br>Metagerontic<br>Paragerontic | Phylogerontic | Paracme. |

With the embryonic stage the paleontologist can do nothing except the very last substage or phylembryo, when molluscs, brachiopods, and other groups begin to secrete their shell; but all later stages are easily accessible in well preserved material.

A classic example of correlation of ontogeny with phylogeny is the genealogy of the Prolecanitidæ, worked out by Karpinsky[1], who has shown that the Carboniferous genus *Pronorites* goes through the following stages: latisellate protoconch, phylembryonic; with the second suture it becomes an *Anarcestes*, nepionic; about the end of the first revolution the *Ibergiceras* stage begins, the end of the larval period; the second revolution corresponds to *Paraprolecanites*, neanic; on the third whorl begins the *Pronorites* stage, adult. Thus with regard to *Pronorites* the genus *Anarcestes* is phylonepionic, *Ibergiceras* is phyloparanepionic, *Paraprolecanites* is phyloneanic. In the same work Karpinsky shows that *Medlicottia* is a direct descendant of *Pronorites*, and in its development goes through all the stages of the ancestral genus and adds still others. The first revolution of *Medlicottia* could not be studied, but the second corresponded to *Ibergiceras*, metanepionic; on the third whorl was seen the *Paraprolecanites* stage, paranepionic; at end of the third whorl the *Pronorites* stage, beginning of the neanic; on the fourth whorl the *Sicanites* stage, end of neanic; on the fifth whorl *Promedlicottia*, anephebic; and lastly, at end of the fifth whorl, *Medlicottia*, adult in characters, though not yet in size.

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[1] Mém. Acad. Sci. St. Pétersbourg, 7th Sér., Tome XXXVII, No. 2. "Ammoneen der Artinsk-Stufe."

In a recent paper the writer[1] has shown that *Glyphioceras* in its development goes through ammonoid stages from *Anarcestes* and *Tornoceras* as a larva, through *Prionoceras* in the adolescent stage, until at diameter of six millimetres it becomes a full-fledged *Glyphioceras*.

## LAW OF ACCELERATION OF DEVELOPMENT.

The study of ontogeny would have little interest and meaning if the law of acceleration of development were unknown. This principle was first used by Louis Agassiz as an aid in the systematic study of biology, but it was reserved for Alpheus Hyatt to formulate the law, and to strengthen theory with practical examples based on the study of cephalopods.[2] An exact and comprehensive definition of the law of *tachygenesis* is the following: "All modifications and variations in progressive series tend to appear first in the adolescent or adult stages of growth, and then to be inherited at earlier and earlier stages according to the law of acceleration, until they either become embryonic or are crowded out of the organization, and replaced in the development by characters of later origin."[3] And in a later paper Professor Hyatt has given a more definite statement: "The substages of development in ontogeny are the bearers of distal ancestral characters in inverse proportion, and of proximal ancestral characters in direct proportion to their removal in time and position from the protoconch, or last embryonic stage."[1]

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[1] Proc. Cal. Acad. Sci., 3d Ser., Geol., Vol. I, No. 3. "The Development of Glyphioceras and the Phylogeny of the Glyphioceratidæ."

[2] Mem. Boston Soc. Nat. Hist., Vol. I, 1866-7; Proc. Boston Soc. Nat. Hist., Vol. I, 1866. "Parallelism of Individual and Order among the Tetrabranchiate Mollusks."

[3] A. Hyatt, "Genesis of the Arietidæ," Preface, p. IX.

The life history of the ammonites is the best example of the law of tachygenesis; these branched off from the nautiloids near the beginning of Devonian time, continued increasing, diverging, became highly specialized and accelerated until their final extinction at the end of Cretaceous time. Each ammonite goes through a larval history that is long and varied in direct proportion to the length of time from its period back to the Lower Devonian. Thus the Nautilinidæ, the first of the new stock, have a comparatively simple ontogeny, there being no great changes from the larval up to the adult stages. The higher Devonian and Carboniferous forms go through several generic changes before they become adults, and Mesozoic genera have still longer larval and adolescent periods; that is, longer in the sense of more complicated.

A distinct addition to this principle has been made in Cope's idea of *retardation*, by which is explained the separation in the ontogeny of the descendant of characters that occurred simultaneously in the ancestor. Cope says: "The *acceleration* in the assumption of a character, progressing more rapidly than the same in another character, must produce, in a type whose stages were once the exact parallel of a permanent lower form, the condition of *inexact parallelism*. As all the more comprehensive groups present this relation to each other, we are compelled to believe that acceleration has been the principle of their successive evolution during the long ages of geologic time. Each type has, however, its day of supremacy and perfection of organism, and a retrogression in these respects has succeeded. This has no doubt followed a law the reverse of acceleration, which has been called retardation. By the increasing slowness in the growth of the individuals of a genus and later assumption of the characters of the latter, they would be successively lost."[2]

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[1] Proc. Amer. Phil. Soc., Vol. XXXII, No. 143, p. 405

[2] "Origin of the Fittest," p. 142.

Dr. R. T. Jackson has recognized the value of this principle of retardation in his studies of the pelecypods,[1] and the writer has noted it in unpublished observations on the ontogeny of many species of ammonites.

The law of tachygenesis was first used by Hyatt in the study of cephalopods, and has since been applied successfully to the pelecypods by Jackson; to the echinoderms by Jackson[2]; to the brachiopods by Beecher, J. M. Clarke, and Schuchert[3]; to the crustaceans by Beecher.[4] It is therefore no longer a theory, but a fixed principle of biology, to be used regardless of any bias towards theories of natural selection or adaptation. It is, however, quite true that all workers in paleontogeny are decided adherents of the Neo-Lamarckian school. A summary of the principles and methods of ontogenetic research has been given by the writer in a recent paper.[5]

## Family LYTOCERATIDÆ *Neumayr.*

The Lytoceratidæ, as defined by Zittel,[6] contain forms with wide, shallow, umbilici, evolute, scarcely embracing whorls, smooth except for constrictions, fine striæ of growth, and occasional ribs made by varices. They have a divided siphonal lobe, two principal lateral, with almost no auxiliary lobes. Body chamber one-half to two-thirds of a revolution.

In this group are included species from the Upper Trias to the Upper Cretaceous, most of the abnormal retrograde genera such as *Turrilites*, *Baculites*, *and Hamites* being placed here. Paleontologists are not agreed as to the relations of this family with the Phylloceratidæ, some regarding it as descended from that family, others as the ancestral stock from which they sprang, and others still regarding both as widely divergent branches from the Prolecanitidæ.

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[1] Mem. Boston Soc. Nat. Hist., Vol. IV, No. 8, "Phylogeny of the Pelecypoda," p. 381.

[2] Bull. Geol. Soc. Amer., Vol. VII, 1895, "Studies of Palæechinoidea."

[3] Amer. Jour. Sci., Vol. XLIV, Aug., 1892, "Development of Brachiopoda, Part II"; Trans. Conn. Acad. Sci., Vol. IX, March, 1892; and Proc. Biol. Soc. Washington, Vol. VIII, July 13, 1893.

[4] Amer. Jour. Sci., Feb. and March, 1897, and Amer. Geol., Vol. XVI, Sept., 1895.

[5] Jour. Geol., Vol. V, No. 5, July-August, 1897. "Comparative Study of Palæontogeny and Phylogeny."

[6] Handbuch d. Palæont, Bd. II, 1885, p. 440.

## Genus **Lytoceras** *Suess.*

*Lytoceras* in the strictest sense comprises species with wide, shallow, umbilicus, whorls little embracing, and shell rather smooth except for fine ribs made up largely of the striæ of growth, and occasional varices and constrictions; they have a divided siphonal lobe, two lateral and one auxiliary lobe.

It ranges from the Lias to the Upper Cretaceous. According to Steinmann[1], *Lytoceras* is probably descended from *Monophyllites*, classed by many naturalists with the Phylloceratidæ. Zittel[2] in his latest work considers the Lytoceratidæ as direct descendants of the Prolecanitidæ, and therefore not from *Monophyllites*, which he assigns to the Cyclolobidæ. E. von Mojsisovics[3] says that *Lytoceras* sprang from *Monophyllites* s. str., and that *Phylloceras* came from *Mojsvarites*, a subgenus under that same group.

All that has been done on the ontogeny of this genus is the work of Branco[4], who described and figured some of the larval and adolescent stages of *Lytoceras germaini* but did not give the complete development, nor compare these stages with antecedent genera. On the same plate Branco figures some larval stages of (*Lytoceras*) *simonyi* Hauer, but this species belongs to *Monophyllites*. Neumayr considered *Turrilites*, *Baculites*, and several other abnormal ammonoids as derivatives from the Lytoceratidæ; and indeed the larvæ of *Baculites*, as figured by Amos Brown[5], do resemble very closely those of *Lytoceras*, as do also those of certain *Scaphites*, according to unpublished observations of the writer. It is quite likely, however, that *Scaphites* is not monophyletic.

### **Lytoceras alamedense,** sp. nov.

PLATES XVI-XVIII.

This species is evolute, with wide, shallow umbilicus and coils that increase very slowly in size, thus scarcely embracing the preceding. The shell is almost smooth, but has fine sinuous cross-striæ of growth that bend forward on the abdomen, form a broad backward bend or lobe on the abdominal shoulders, and another forward sinus on the sides. These are exactly parallel to the mouth, which is marked by varices and constrictions. The growth lines scarcely show on internal casts, but the constrictions are quite distinct, showing them to have been formed by thickening the lip of the aperture during periodic cessations of growth. The sculpture of the shell is shown on Pl. XVII, fig. 4, diameter 7.50 mm., three and three-quarters whorls, seven times enlarged. The shell is not smooth during all the stages; up to the end of the first coil it is smooth, then comes a deep constriction, and for an entire coil the shell is ornamented with relatively coarse, single cross-ribs, which end abruptly, and are represented in later growth by occasional irregular varices. The spiral of the adult is shown on Pl. XVII, fig. 6, and a cross-section, early adult stage, on fig. 1.

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[1] Elemente d. Pal., 1890, p. 420.

[2] Grundzuege d. Pal., 1895, p. 435.

[3] Denk. K. Akad. Wiss. Wien, Bd. LXIII, 1896, p. 95.

[4] Palæontographica, Vol. XXVI, Beitr. Entwick. Foss. Cephal., Pl. VIII, fig. 6.

[5] Proc. Acad. Nat. Sci. Phila., 1891, p. 159, and 1892, p. 136.

The septa are like those usually found on *Lytoceras*, a long, divided siphonal lobe, two principal lateral lobes divided into two parts, and an auxiliary lobe on the umbilical border, divided into several small secondary lobes. This is really a part of the internal lateral lobe. All the lateral saddles are deeply divided. Pl. XVIII, fig. 14, shows the outside septa of the largest specimen where they were visible, diameter 7.00 mm.

It is quite likely that the adult grows considerably larger than any specimen obtained, and that the septa grow more complicated than this, but they would undoubtedly be very like these, for they already bear the stamp of maturity. The internal septa at this size could not be made out in detail.

The largest specimen obtained was only 14.5 mm. in diameter, but from about six millimetres up there is little change, so that larger sizes, if found, will probably be like those figured and described in this paper. The cross-section (Pl. XVII, fig. 1) shows that successive whorls become only very gradually higher, and the abdominal shoulders less rounded, so that there is small likelihood of failure to recognize larger specimens of this species. The only other species with which *Lytoceras alamedense* might be confused is an undescribed form collected by Mr. F. M. Anderson at the Forty Nine mine, near Phœnix, Oregon, and that has a lower, broader whorl, and deeper umbilicus at the same size. The young stages of *L. batesi* Trask are slenderer, with rounded aperture like the adult, but with simple adolescent lobes at diameter of 10 mm., and even at that stage almost no impressed zone. They have many constrictions, which run straight across the whorl, and lack the sinuosity so characteristic of *L. alamedense.* The striæ of growth also run straight across, parallel to the constrictions.

A striking characteristic of *L. alamedense* is the contraction of the chambers after the first whorl, causing a bulging of the protoconch and part of the first coil. This is shown in the cross-section, Pl. XVII, fig. 1, and especially in the larvæ on Pl. XVI, figs. 7 and 8, 9 and 10.

*Horizon and Locality:—Lytoceras alamedense* was found by Dr. L. G. Yates on the Arroyo del Valle, eight miles southeast of Livermore, Alameda county, California, in calcareous sandstone thought to belong to the upper Horsetown beds, the top of the Lower Cretaceous. Associated with it are *Phylloceras onoënse* Stanton, *Lytoceras batesi* Trask, *Desmosceras hoffmanni* Gabb, *Haploceras breweri* Gabb, *Hoplites remondi* Gabb, *Hoplites* nov. sp. off *H. dufrenoyi* d'Orb. of the Gault of France, *Baculites occidentalis* Gabb, and other species not quite so characteristic. The writer has not visited the locality in person, and so cannot vouch for the occurrence of all these species in the same beds. Mr. E. B. Kimball of Haywards at the request of the writer recently made an excursion to the locality, but could find only beds with *Baculites occidentalis* and *B. chicoënsis.* It seems to the writer to be likely that both horizons are present in such close proximity that they were not differentiated in collecting, or possibly the beds may be transitional from Horsetown to Chico.

## ONTOGENY.

*Phylembryonic stage.*—The first stage in reach of the paleontologist is the protoconch, representing the earliest shell secreted by the shell gland. The class or phylum is already recognizable, but it is not possible to do more than compare this stage with the primitive cephalopod. What that was is unknown, although *Tentaculites* has been thought by some naturalists to be the radicle of the group. It is purely arbitrary to assign the protoconch to the end of the embryonic stage, but some division must be made, and it is made here for convenience, although certainly a part of the spiral tube was taken up by the embryo. There is a remarkable constancy in the size and shape of the protoconch in all the later ammonoids; in all of them it is a smooth, oval body, about one-half millimetre in diameter and three-quarters in breadth. The protoconchs of the earlier ammonoids were almost spherical, but the oval form was soon developed and became a fixed stage, while other stages that came later were entirely lost in ontogeny. This is the only case known to the writer where ammonites in their development skip over certain stages, but it is true of nearly all later Mesozoic genera. In fact, two species of the same genus often do not agree in omission of stages of growth. Some species of *Schlœnbachia*, for instance, go through in regular order all stages from *Anarcestes* up to *Glyphioceras;* others, on the contrary, omit all stages (so far as any record of them in the shell is concerned) between the protoconch and *Glyphioceras*, reaching that at the second septum. The writer has noted that while different individuals of the same species are remarkably constant in reaching the same stage at the same dimensions, especially in the larval period, different species even though very nearly related, usually differ very much in dimensions at corresponding stages. This difference grows more pronounced in the adolescent period, until decided specific characters appear. In other words, specific difference is merely exaggerated individual variation, and this in turn is merely unequal acceleration or retardation of the appearance of certain characters. All variation would seem, then, to depend on Cope's law.

The protoconch of *Lytoceras alamedense* (Pl. XVI, figs. 1 and 2) has a diameter of 0.56 mm., and width of 0.81 mm; in the protoconch is seen the pear-shaped siphonal cæcum or knob at the beginning of the siphuncle (Pl. XVI, fig. 4). This is surely an embryonic feature, being present before the development of the first septum, and probably represents the shrunken, horny covering of the nautiloid embryos, while the calcareous shell of the protoconch is an ammonoid character pushed back by acceleration of development until it occurs simultaneously with nautiloid characters. No trace of a prosiphon could be seen on any specimen, although some were nearly as transparent as glass and would surely show this organ in transmitted light.

*Ananepionic.* With the appearance of the first septum (Pl. XVIII, fig. 1) the animal becomes not merely a cephalopod, but a chambered nautilian shell, and this is regarded as the beginning of the larval period proper. As shown on Pl. XVI, figs. 3 and 4, this suture consists of a rather narrow, rounded, siphonal saddle, flanked by a narrow, lateral lobe and broader, lateral saddle. This stage corresponds to some Silurian nautiloid, and while constant in all ammonoids is of equally short duration in all, lasting for only one septum.

*Metanepionic.* At the second septum the shell enters the second larval stage, is no longer a nautiloid, but with the development of a siphonal lobe becomes an ammonoid. As Hyatt[1] has shown, this stage has in most ammonites, especially the older forms, an undivided abdominal lobe like that of the Nautilinidæ of the Lower Devonian; but in many later and more highly accelerated genera the stages corresponding to the older goniatites are omitted. Thus in *Lytoceras alamedense* (Pl. XVIII, fig. 2, and Pl. XVI, figs. 4 and 5) at the second septum the abdominal lobe is developed, but it is already divided by a siphonal saddle; this Hyatt thinks corresponds to the Primordialidæ of the Upper Devonian; but all the older goniatites are retrosiphonate, and only in extreme maturity of some late forms like *Glyphioceras* do the siphonal collars point forwards. Now *L. alamedense* is prosiphonate at the second septum, so that this stage cannot correspond to the Primordialidæ, but rather to some of the late transitional goniatites, or to some of the early simple ammonites of the Permian. The shape and external septum resemble *Glyphioceras*, but that genus has only one internal lateral lobe on each side of the antisiphonal, and the metanepionic stage of *L. alamedense* shows two (Pl. XVIII, figs. 2 and 3, 4 and 5). This character suggests some early ammonite derived from the Prolecanitidæ, differing from the goniatite stock in being prosiphonate.[1] Such a form is seen in *Nannites*, named by Mojsisovics[2] to include some smooth, rounded species with simple goniatitic septa, from the Upper Trias, *Goniatites spurius* Muenster being the type. These forms while not ammonitic in sutures or ornamentation of the shell are prosiphonate. The septa consist of a divided ventral lobe, two external lateral lobes on each side, an internal undivided antisiphonal lobe, and two on each side.

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[1] "Phylogeny of An Acquired Characteristic," pp. 414 and 415.

The ontogeny of *Nannites* is unknown, but it probably comes from some member of the Prolecanitidæ; until recently it was not known below the Upper Trias, but Dr. Carl Diener[3] has discovered it in the *Otoceras* fauna of the Lower Trias of the Himalayas; thus *Nannites* must be a survivor of the Permian ammonite fauna, with which, indeed, it agrees in its chief characters rather than with Triassic faunas. *N. hindostanus* Diener (*op. cit.* Pl. VII, figs. 3, 11, 12) is broad, with low whorl, open umbilicus, simple goniatitic lobes and saddles, and shell marked by contractions forming transverse ridges and furrows; between these contractions the shell is covered with fine striæ of growth. The shell laminæ are cut off by the contractions, and sink under the laminæ in front, causing what Diener calls "direct imbrication."

*Nannites* was classed by Mojsisovics with the Ptychitidæ, but the genus was raised by Diener to a subfamily Nannitinæ; no connection with the Lytoceratidæ has ever been suggested, but the results of this investigation make it quite probable. *L. alamedense* at the second septum enters a stage resembling *Nannites* (Pl. XVI, figs. 3 and 4), and continues in this for an entire revolution, to diameter 1.21 mm. (figs 5 and 6), during which time it is smooth, low-whorled, broad, with narrow umbilicus. The forward pointing siphonal collars are plainly visible in some specimens, at first short, reaching only about one-sixth of the distance toward the next septum. At one-third of a coil it extends one-fifth forward, and at one and one-fourth coils it extends one-third of the distance toward the next septum.

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[1] In a recent paper, Mém. Soc. Géol. France. Mém. XVIII, 1898, "Etudes sur les Goniatites," Professor E. Haug derives the Lytoceratidæ from *Gephyroceras*.

[2] Abhand. K. K. Geol. Reichsanstalt, Wien, Bd. X, 1882, p. 210.

[3] Mem. Geol. Survey, India, Pal. Indica, Ser. XV, Vol. II, Part I, p. 66.

*Paranepionic.* At the end of the first whorl a deep constriction marking a temporary mouth of the shell makes its appearance, and the surface ceases to be smooth, takes on fine cross-ribs with fine striæ of growth between them (Pl. XVI, figs. 7 and 8), and at the same time the umbilicus widens. The whorl narrows perceptibly, causing the protoconch and first coil to bulge out, as shown on Pl. XVI, fig. 9 and Pl. XVII, fig. 1.[1] The septa are still goniatitic, and as long as that lasts, up to one and one-third coils, the shell resembles *Nannites hindostanus* Diener; but shortly after the end of the first coil at diameter of 1.58 mm., one and one-twelfth coils, the two internal, lateral lobes begin to coalesce (Pl. XVIII, fig. 6), showing a departure from the *Nannites* stage. At one and one-third coils, diameter 1.81 mm., the two lobes have grown into one, and the siphonal lobe becomes slightly notched (Pl. XVIII, fig. 7), that is, begins to be ammonitic. The sculpture remains just the same from the end of the first whorl to that of the second (Pl. XVI, figs. 7 and 8, 9 and 10), but progression is very apparent in the development of the septa. Hyatt[2] says that the limits between the larval and adolescent stages in the Lytoceratinæ should be drawn where the septa become ammonitic. To do this here would be artificial, for the sculpture lasts until the end of the second whorl, then stops suddenly, marking a distinct change regarded as the end of the larval period. At diameter of 1.87 mm., one and five-twelfths coils (Pl. XVIII, fig. 8), the lateral lobe becomes indented and the saddles somewhat irregular; at diameter of 2.00 mm., one and seven-twelfths coils (fig. 9), this is more pronounced; at diameter of 2.03 mm., one and two-thirds coils (fig. 10), the threefold division of the first lateral lobe is seen; at two coils, diameter of 2.37 mm. (fig. 11), the lobes and saddles, while still comparatively simple, show all the main characters of the Lytoceratidæ, and as the sculpture ends here this may justly be taken as the end of the larval stage.

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[1] This stage resembles *Pericyclus* of the Lower Carbouiferous, but probably there is no real kinship.

[2] "Phylogeny of An Acquired Characteristic," p. 416.

The paranepionic sculptured whorl may then be divided into two distinct periods: first, that part which has simple goniatitic septa, lasting one-third of a coil; secondly, that part with ammonitic septa, beginning at one and one-third coils and lasting two-thirds of a revolution. This in turn might be subdivided into several subordinate divisions based on increasing complexity of the septa. No descendants of *Nannites* with which this part of the larval stage could be correlated are known.

### *Adolescent Stages.*

When the sculpture dies away and the shell becomes smooth again, the adolescent period may be said to have begun. This happens at the end of the second whorl, and was found on a number of specimens, to be constant at diameter 2.3 mm. On Pl. XVI, figs. 11 and 12, is shown the beginning of this stage, and the corresponding septa on Pl. XVIII, fig. 12. On this specimen the first whorl is smooth (metanepionic), the second sculptured, although since the outer shell is broken off from most of the surface the sculpture is indistinct and shows itself chiefly in undulations rather than ribs on the cast. The characters of the family Lytoceratidæ have now appeared, and this beginning of the neanic period represents *Monophyllites* of the Trias, and closely resembles the group of *M. suessi* Mojsisovics, characterized by the presence of two lateral and one auxiliary lobe. Mojsisovics[1] says that *Lytoceras* comes from the group of *Monophyllites sphærophyllus* Mojs., but that group has two or three auxiliary lobes and could not have given rise to the simpler form without showing the reduction in ontogeny.

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[1] Denk. K. Akad. Wiss. Wien, Bd. LXIII, 1896, p. 95.

It was not found convenient to subdivide the adolescent stage, for the reason that there was no marked change in the surface or shape of the whorl. The septa become gradually more complex until near the end of the third coil they are transitional from *Monophyllites* to *Lytoceras* (Pl. XVII, figs. 2 and 3; Pl. XVIII, fig. 13). This stage lasts for about two revolutions, until near the end of the fourth coil.

### *Ephebic Stage.*

No line can be drawn between the adolescent and adult stages in this species, for the only change is in the gradually increasing digitation of the septa. At three and three-quarters coils, diameter of 7.50 mm., the septa are already typical of *Lytoceras* (Pl. XVIII, fig. 14), while the form has changed little, except that the whorl is slightly higher in proportion to its width (Pl. XVII, fig. 4). The shell is smooth except for the fine cross-striæ and occasional varices. The involution, always slight, becomes almost nothing, and the whorl is somewhat squarer. Pl. XVII, fig. 6, shows the spiral of the largest specimen obtained, diameter of 14.5 mm., with the relative height of whorl and width of umbilicus the same as in the adolescent period. The siphonal collars now reach three-fourths of the distance forward towards the next septum, longer than those described from any other ammonite. These certainly are separate organs and not merely a prolongation of the septal walls.

## TABLE OF STAGES OF GROWTH.

| | *Phyt-em-bry-onic.* | *Nepionic.* | | | | *Neanic.* | | | | *Ephebic.* | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pro-to-conch | ⅔ coil. | 1 coil. | 1⅓ coils. | 1⅔ coils. | 2⅓ coils. | 2⅝ coils. | 3⅛ coils. | 3⅜ coils. | 3¾ coils. | 5 coils. |
| Diameter . . . . . . | mm.<br>0.56 | mm.<br>1.04 | mm.<br>1.21 | mm.<br>1.81 | mm.<br>2.15 | mm.<br>3.00 | mm.<br>3.90 | mm.<br>4.52 | mm.<br>6.40 | mm.<br>7.50 | mm.<br>14.50 |
| Height of last whorl. | | 0.41 | 0.45 | 0.58 | 0.62 | 0.95 | 1.05 | 1.58 | 2.26 | 2.50 | 4.70 |
| Height of last whorl from preceding. . | | 0.30 | 0.38 | 0.50 | 0.52 | 0.80 | 0.82 | 1.22 | 1.37 | 1.90 | 4.30 |
| Width. . . . . . . . | 0.81 | 0.86 | 0.81 | 1.13 | 1.16 | 1.37 | 1.85 | 2.07 | 2.48 | 3.10 | 5.20 |
| Involution . . . . . | | 0.11 | 0.07 | 0.08 | 0.12 | 0.15 | 0.23 | 0.36 | 0.89 | 0.40 | 0.40 |
| Width of umbilicus. | | 0.20 | 0.43 | 0.95 | 0.98 | 1.40 | 1.97 | 2.04 | 2.30 | 3.30 | 6.20 |

## MEASUREMENTS OF CROSS-SECTION.

| | *Nepionic.* | | | | *Neanic.* | | | | *Ephebic.* |
|---|---|---|---|---|---|---|---|---|---|
| | Prot. and ⅛ coils. | Prot. and ⅓ coils. | 1⅛ coils. | 1⅝ coils. | 2⅛ coils. | 2⅝ coils. | 3⅛ coils. | 3⅝ coils. | 4⅛ coils |
| Diameter . . . | mm.<br>0.81 | mm.<br>1.10 | mm.<br>1.55 | mm.<br>2.08 | mm.<br>2.72 | mm.<br>3.66 | mm.<br>4.88 | mm.<br>6.53 | mm.<br>8.60 |

## Genus **Phylloceras** *Suess.*

*Phylloceras*, as defined and restricted by Zittel and Steinmann, comprises involute, compressed, high-whorled species, with smooth sides, rounded abdomen, and narrow umbilicus. The septa are branching, leaf-like, have three or four lateral, and at least as many more external auxiliary lobes.

This genus in its typical form appears first in the Lower Jura, but its forerunners are known in the Trias; Zittel[1] says it developed out of *Megaphyllites*, which he assigns to the Cyclolobidæ; Steinmann[2] agrees with Zittel in this, and further derives the family Phylloceratidæ from the goniatite group Prolecanitidæ. J. F. Pompeckj[3] says that *Phylloceras* in its ontogeny goes through stages corresponding to *Megaphyllites* and *Monophyllites*, subgenus *Mojsvarites*, basing his statements on the drawings of Branco. The latest published opinion is that of E. von Mojsisovics[4], who derives *Phylloceras* through *Rhacophyllites* from *Mojsvarites;* he says that *Megaphyllites* belongs to a group with accelerated development betokening degeneration, and that it, with its closed umbilicus, could not have been the ancestor of *Phylloceras* with open umbilicus. From all this it may be seen that there is almost as little agreement about the derivation of *Phylloceras* as of *Lytoceras*.

The only ontogenetic studies yet published on the Phylloceratidæ have been made by Branco[5], on *Megaphyllites insectum* Mojs., protoconch and four septal stages (*op. cit.*, Pl. VII, fig. 4); *M. humile* Mojs. (Pl. VIII, fig. 1), protoconch; *Phylloceras heterophyllum* Sowerby (Pl. IX, fig. 1), protoconch and part of the larval stages; *P. tatricum* (fig. 2), protoconch; *Rhacophyllites tortisulcatus* d'Orb. (fig. 3), protoconch and early larval stages. On these few data have been based all the speculations as to the phylogeny of *Phylloceras*, in so far as they have been based on ontogenetic study at all. Branco and most of the other writers on this subject have assumed that the protoconch is the important stage in ontogeny, and have neglected the later stages. But the protoconch is a fixed stage, remarkably constant in all the later ammonoids, while what Hyatt calls epembryonic stages, and especially the larval and early adolescent stages, are really the important ones; they show most distinctly the characters of ancestral genera.

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[1] Handbuch d. Pal., Bd. II, 1885, p. 436.

[2] Elemente d. Pal., 1890, p. 418.

[3] N. Jahrb. f. Mineral, Bd. II, 1895, pp. 19 and 22, "Ammoniten des Rhät."

[4] Denk. K. Akad, Wiss. Wien, Bd. LXIII, 1896, p. 95, "Ceph. Ob. Trias des Himalayas."

[5] Palæontographica, Bd. XXVI, "Beitr. Entwick. Foss. Cephalopoden."

## **Phylloceras onoënse** *Stanton.*

PLATES XIX AND XX.

*Phylloceras ramosum* GABB, Pal. Cal., Vol. I, p. 65, Pl. XI, fig. 12; Pl. XII, fig. 12.
*Phylloceras onoënse* STANTON, Bull. 133, U. S. Geol. Survey, p. 74.
(Not *P. ramosum* MEEK, Bull. Geol. and Geog. Survey Terr., Vol. II, No. 4, p. 371.)

This species from the Horsetown beds of the Lower Cretaceous was identified by Gabb with Meek's species from the Upper Cretaceous of Puget Sound. But Dr. Stanton has recently broken this up into three species in a genetic series, *P. knoxvillense* Stanton, from the Knoxville beds, Lower Cretaceous; *P. onoënse* Stanton, Horsetown beds, Gault; and the real *P. ramosum* Meek, from the Upper Cretaceous. Stanton says that *P. onoënse* differs from *P. knoxvillense* in lacking constrictions, but these were observed on several specimens from Cottonwood creek, Shasta county, and from Alameda county.

### ONTOGENY.

*Larval stages.*—No protoconch was separated from the later chambers, but its shape can easily be seen on Pl. XIX, fig. 1, and Pl. XX, fig. 1. It is very like that of *Lytoceras alamedense.* The ananepionic stage, shown by the nautiloid septum (Pl. XX, fig. 1), shows a broader and longer abdominal saddle than *Lytoceras*, but is otherwise like it; the pear-shaped siphonal cæcum or knob could be seen clearly inside of the protoconch. The metanepionic stage lasts only through the second septum (Pl. XX, fig. 1); it has an undivided, rounded, ventral lobe, and two external lateral lobes, and probably corresponds to the stock Prolecanitidæ, from which *Phylloceras* came.

With the third septum comes the divided ventral lobe of the paranepionic stage (Pl. XX, fig. 1); this agrees with the *Nannites* stage of *Lytoceras*, and probably shows the connection with that genus. This stage lasts up to diameter of 1.15 mm., one and five-twelfths coils, is smooth except for a constriction at end of the first coil. Its lobes are shown on Pl. XX, figs 1 and 2, and the shell on Pl. XIX, figs. 2 and 3. Even at this early stage the tendency to form auxiliary lobes shows itself, in contradistinction to *Lytoceras*. At one and one-sixth coils, diameter of 0.87 mm., the second internal lateral lobe has divided into two, the outer of which soon gets above the umbilical margin. This goes on repeating itself in later stages until a large number of auxiliary internal and external lobes have been formed. The first part of the paranepionic stage lasts up to one and five-twelfths coils, but the umbilicus is always wider than at corresponding stages of *Lytoceras*, and the resemblance to *Nannites* not nearly so great. At this time the lobes begin to be slightly ammonitic, and at one and three-quarters coils, diameter of 1.42 mm. (Pl. XX, fig. 3), are already decidedly so. The species has now parted company with *Lytoceras*, for the lobes are too numerous, and the sculptured stage of that genus is never reached.

Towards the end of the second whorl this form has a moderately wide umbilicus and ammonitic lobes, and then seems to be transitional to that group of *Monophyllites* with several lateral lobes; but at the beginning of the third coil the umbilicus becomes narrower, the last whorl higher and more compressed, and the shell resembles *Megaphyllites*, a Triassic genus which has been shown by Branco[1] to go through in its development stages of growth somewhat like those described for *Phylloceras*. This is the adolescent period, and is shown on Pl. XIX, figs 6–8 and Pl. XX, figs. 4 and 5. Shortly after this the septa become still more complex, transitional to *Phylloceras* (Pl. XIX, fig. 9, and Pl. XX, fig. 6), although the adolescent period does not end abruptly, but at diameter of 7.00 mm. is still quite apparent (Pl. XIX, fig. 10, and Pl. XX, fig. 7). At 10.00 mm. diameter the outline and septa are already characteristic of *Phylloceras*, and even of this particular species, as shown on Pl. XIX, fig. 11. The adult septa shown on Pl. XX, fig. 8, were traced from two photographs, at diameter of 35.00 mm.; these do not agree perfectly with those figured by Gabb, but in the photograph there was no chance for error as in free-hand sketching. The number and position of the internal lobes are merely indicated by a dotted line, as the details could not be made out.

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[1] Beitr. Entwick, Foss. Cephal., Pl. VII, fig. 4.

## TABLE OF STAGES OF GROWTH.

| | *Larval.* | | | | *Adolescent.* | | | | *Adult.* | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P. & 4 septa | 1⅙ coils. | 1 5/12 coils. | 1¾ coils. | 2⅙ coils. | | | | | |
| | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. |
| Diameter . . . . . . . . | 0.44 | 0.87 | 1.15 | 1.42 | 1.90 | 2.46 | 4.30 | 7.00 | 10.00 | 35.00 |
| Height of last coil. . . . | 0.28 | 0.36 | 0.45 | 0.53 | 1.02 | 1.25 | 2.12 | 3.80 | 6.20 | 18.50 |
| Height of last coil from preceding . . . . . . . | 0.14 | 0.26 | 0.39 | 0.41 | 0.63 | 0.85 | 1.40 | 2.00 | 3.50 | 12.00 |
| Width . . . . . . . . . . | 0.63 | 0.66 | 0.66 | 0.83 | 1.33 | 1.50 | 2.15 | 3.35 | 5.30 | 15.00 |
| Involution. . . . . . . . | 0.16 | 0.10 | 0.06 | 0.12 | 0.39 | 0.40 | 0.72 | 1.80 | 2.70 | 6.50 |
| Width of umbilicus . . . | | 0.27 | 0.41 | 0.48 | 0.38 | 0.53 | 0.60 | 0.65 | 0.50 | 2.00 |

## CONCLUSION.

In the preceding pages it has been shown that *Lytoceras* in its development goes through the following stages: phylembryonic, protoconch representing some unknown cephalopod; ananepionic, representing some Silurian nautiloid; metanepionic, already an ammonite, and corresponding to *Nannites*, or to some other early genus of the Cyclolobidæ; paranepionic, at first corresponding to the sculptured group of *Nannites*, and later transitional to the earlier members of the Lytoceratidæ; neanic, analogous to that group of *Monophyllites* with two lateral lobes, and transitional to the adult characters of *Lytoceras* at diameter of 7.00 mm.

*Phylloceras* begins life just as did *Lytoceras*, coming from the same remote ancestor, and agreeing with that genus in the phylembryonic and ananepionic stages; but at the second septum, metanepionic, it shows the undivided ventral lobe of the Prolecanitidæ, a stage which *Lytoceras* omits. In the paranepionic stage *Phylloceras* also corresponds to some genus like *Nannites*, and continues in this stage up to about one and a quarter coils, although even at this early stage it is distinguished from *Lytoceras* by the tendency to form auxiliary lobes. In the adolescent period *Phylloceras* also goes through a *Monophyllites* stage, but is analogous to that group with narrower umbilicus, and numerous auxiliary lobes, probably to the subgenus *Mojsvarites*. Before the end of the adolescent stage it corresponds to *Megaphyllites* and then by imperceptible transitions, narrowing the umbilicus and complicating the lobes until at 10.00 mm. diameter it becomes a full-fledged *Phylloceras*.

Thus these two genera come from a common origin, and follow the same paths up to *Nannites*, where they part company, each going through a stage corresponding to that genus, but to different species under it; both go through *Monophyllites* stages, but here again analogous to different groups and even different subgenera. There the resemblance ceases, and they develop into different families probably by the middle of the Trias, for in the upper division of that formation *Megaphyllites* and *Monophyllites* are sharply distinguished from each other. In the life-history of these two genera we have a rare opportunity of observing acceleration of development, and divergence of two nearly related stocks, whose history may be traced from the Paleozoic to near the end of the Mesozoic eras.

STANFORD UNIVERSITY,
CALIFORNIA,
May, 1898.

## EXPLANATION OF THE FIGURES.

### PLATE XVI.

Larval Stages of *Lytoceras alamedense*, sp. nov.

Figs. 1, 2. Protoconch, from above, and front, $^{20}/_{1}$.

Figs. 3, 4. Protoconch and two-thirds of a coil, diam. of 1.04 mm., twenty times enlarged. Phylembryonic to metanepionic, twenty times enlarged.

Figs. 5, 6. First whorl, diam. 1.21 mm., metanepionic, twenty times enlarged.

Figs. 7, 8. One and one-third coils, diam. 1.81 mm., metanepionic to to paranepionic, twenty times enlarged.

Figs. 9, 10. One and two-thirds coils, diam. 2.15 mm., metanepionic, through paranepionic, to ananeanic; twenty times enlarged.

Figs. 11, 12. Neanic (adolescent), two and one-third coils, thirteen times enlarged, diam. 3.00 mm.

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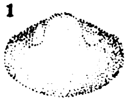

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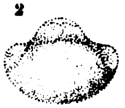

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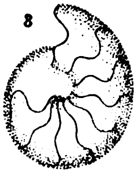

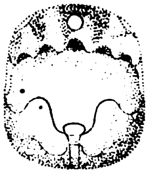
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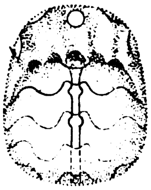

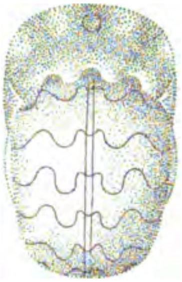
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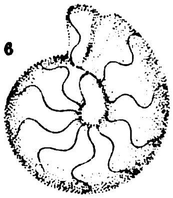

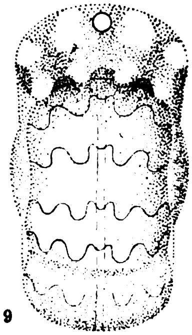
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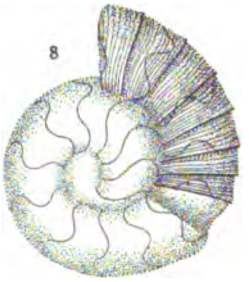

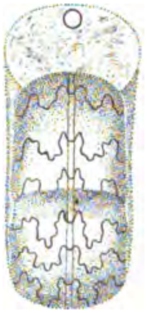
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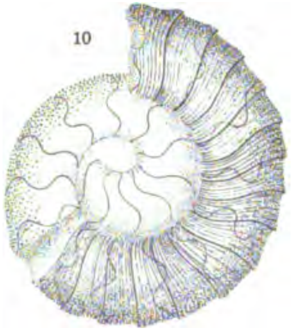
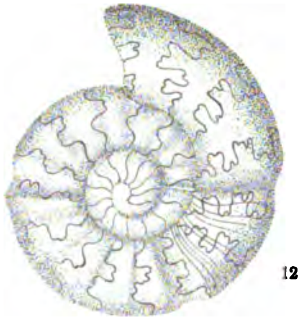




F. H. Smith, Del. Lith. Britton & Rey S.F.

Lytoceras alamedense, sp. nov.

## EXPLANATION OF THE FIGURES.

### PLATE XVII.

*Lytoceras alamedense*, sp. nov.

Fig. 1. Cross-section, early adult stage; diam. 8 mm., ten times enlarged, four and one-eighth coils.

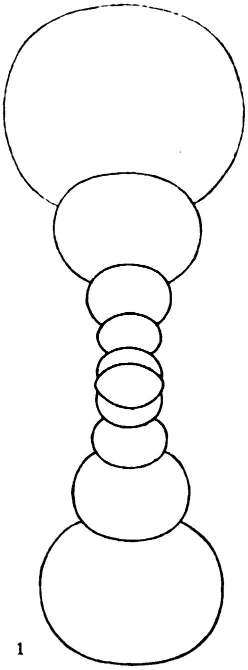
Fig. 2. Spiral, late adolescent stage, diam. 3.90 mm., two and three-quarters whorls, thirteen times enlarged.

Fig. 3. Front outline of the same, diam. 3.90 mm.

Fig. 4. Side view, early adult stage, diam. 7.50 mm., three and three-quarters coils, seven times enlarged.

Fig. 5. Front outline of the above (7.50 mm.).

Fig. 6. Spiral, adult, diam. 14.5 mm., five whorls, four times enlarged.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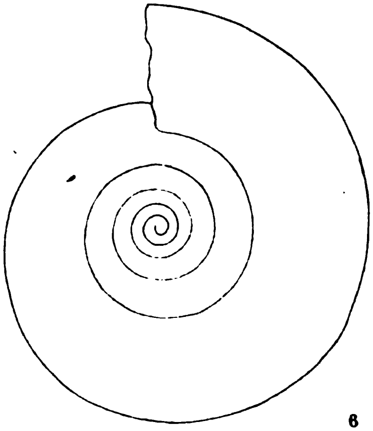
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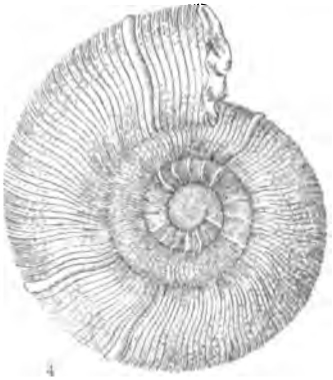
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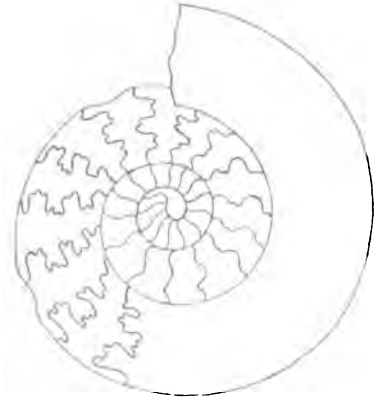
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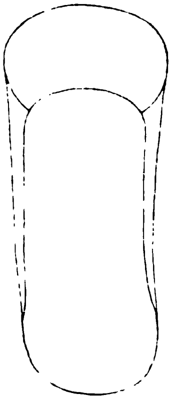
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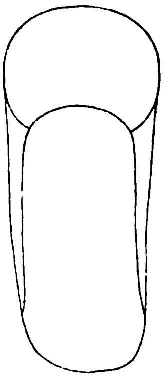
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J. P. Smith, del. Britton & Rey, S.F.

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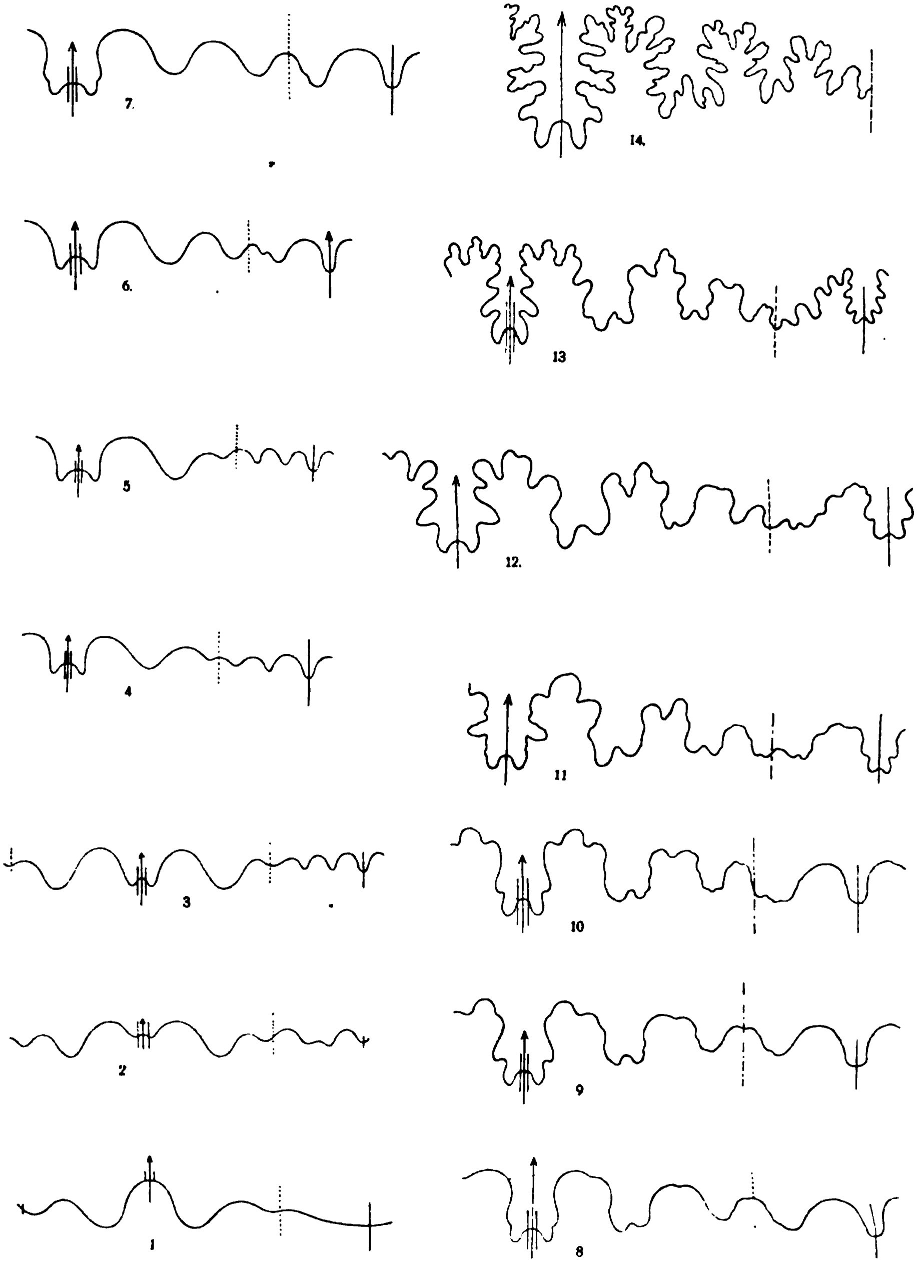
## EXPLANATION OF THE FIGURES.

### Plate XVIII.

Figs. 1–12 are thirty times enlarged; fig. 13 is twenty times enlarged; and fig. 14 is fifteen times enlarged.

Development of the septa of *Lytoceras alamedense*, sp. nov.

Fig. 1. First septum.
Fig. 2. Second septum.
Fig. 3. Seventh septum, one-half coil.
Fig. 4. At two-thirds of a coil, diam. 1.04 mm.
Fig. 5. At one coil, diam. 1.21 mm.
Fig. 6. At one and one-twelfth coils, diam. 1.58 mm.
Fig. 7. At one and one-third coils, diam. 1.81 mm.
Fig. 8. At one and five-twelfths coils, diam. 1.87 mm.
Fig. 9. At one and seven-twelfths coils, diam. 2.00 mm.
Fig. 10. At one and two-thirds coils, diam. 2.03 mm.
Fig. 11. At two coils, diam. 2.37 mm.
Fig. 12. At two and one-third coils, diam. 3.00 mm.
Fig. 13. At two and five-sixths coils, diam. 3.90 mm.
Fig. 14. At three and three-quarters coils, diam. 7.50 mm.



J. P. SMITH, DEL. LITH. BRITTON & REY, S.F.

LYTOCERAS ALAMEDENSE, SP. NOV.

## EXPLANATION OF THE FIGURES.

### Plate XIX.

*Phylloceras onoënse* Stanton.

Fig. 1. Protoconch and three chambers, diam. 0.45 mm., front view, forty times enlarged.

Figs. 2, 3. Larva, one and one-sixth coils, diam. 0.87 mm., forty times enlarged.

Figs. 4, 5. Larva, one and three-fourths coils, diam. 1.42 mm., twenty times enlarged.

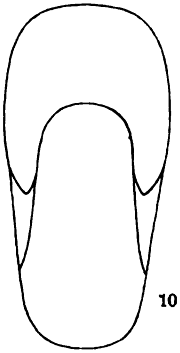
Figs. 6, 7. Transition from larval to adolescent stage, two and one-sixth coils, diam. 1.90 mm., twenty times enlarged.

Fig. 8. Outline at diam. 2.46 mm., twenty times enlarged, adolescent stage.

Fig. 9. Outline at diam. 4.50 mm., thirteen times enlarged.

Fig. 10. Outline at diam. 7.00 mm., seven times enlarged.

Fig. 11. Outline at diam. 10.00 mm., four times enlarged.



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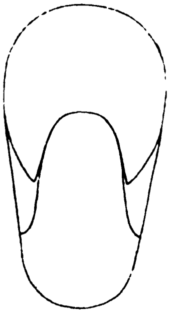

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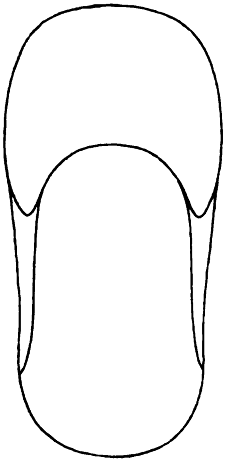

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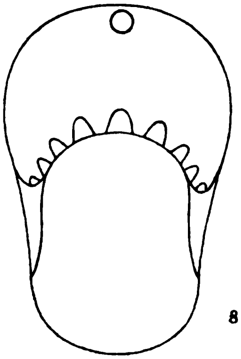

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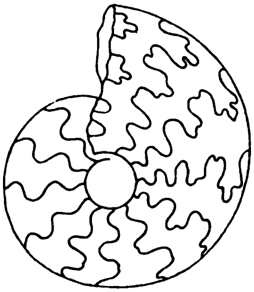

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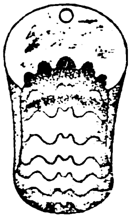

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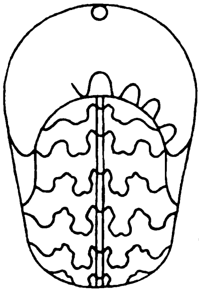

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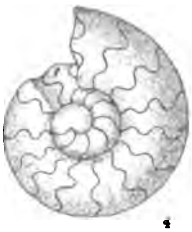

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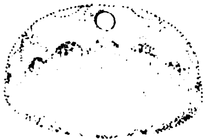

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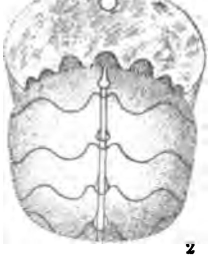

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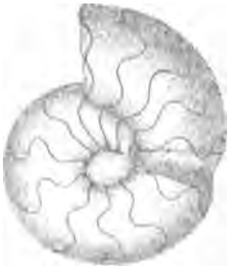

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F. R. SMITH, DEL.

LITH. BRITTON & REY, S.F.

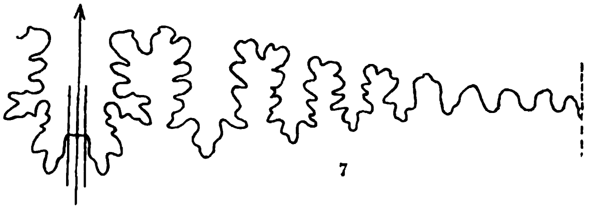
PHYLLOCERAS ONOENSE STANTON

## EXPLANATION OF THE FIGURES.

### PLATE XX.

Development of the Septa of *Phylloceras onoënse* STANTON.

| | |
|---|---|
| Fig. 1. | Protoconch, with the first four septa, drawn as if unrolled, forty times enlarged, transition from phylembryonic, through ana-, to meta-, to para-nepionic. |
| Fig. 2. | Diam. 0.87 mm., one and one-sixth coils, forty times enlarged. |
| Fig. 3. | Diam. 1.42 mm., one and three-fourths coils, transition from larval to adolescent stage, forty times enlarged. |
| Fig. 4. | Diam. 1.90 mm., two and one-sixth coils, forty times enlarged; adolescent. |
| Fig. 5. | Diam. 2.46 mm., twenty times enlarged. |
| Fig. 6. | Diam. 4.50 mm., thirteen times enlarged. |
| Fig. 7. | Diam. 7.00 mm., thirteen times enlarged. |
| Fig. 8. | Diam. 35.00 mm., natural size, adult stage; traced from photographs. |



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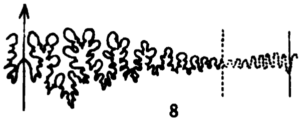

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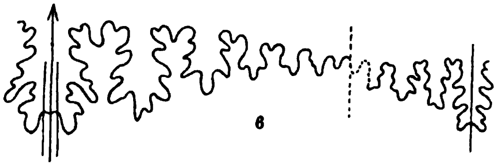

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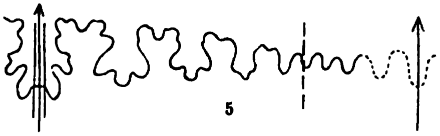

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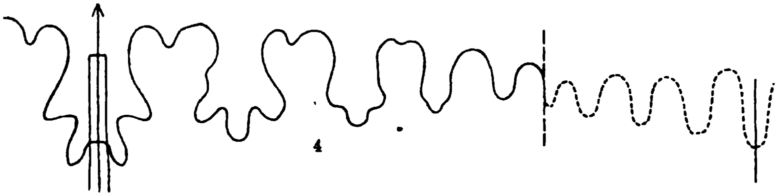

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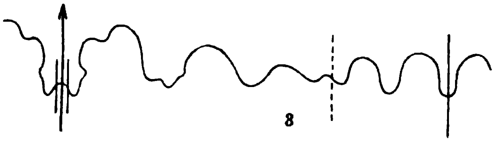

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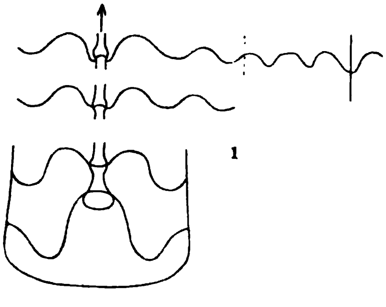

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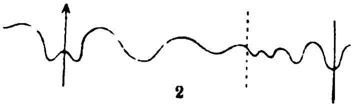

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F. H. SMITH, DEL. BRITTON & REY, S.F.

PHYLLOCERAS ONOENSE STANTON

CONTRIBUTIONS TO BIOLOGY
FROM
THE HOPKINS SEASIDE LABORATORY
OF THE
LELAND STANFORD JR. UNIVERSITY

## XVII

# Phycological Memoirs.

BY
DE ALTON SAUNDERS.

Reprinted from the Proceedings of the California Academy of Sciences,
3d Ser., ~~Geol.~~, Vol. I.
Bot.

SAN FRANCISCO, CAL.
1898

# PREFATORY NOTE.

This memoir is the seventeenth of a series designed to illustrate investigations and explorations connected with the Hopkins Seaside Laboratory, an adjunct of the biological laboratories of the Leland Stanford Junior University. These investigations have been carried on by means of the assistance given by Timothy Hopkins, Esq., of Menlo Park, California. This memoir appears in the publications of the California Academy of Sciences, the present edition being a reprint.

OLIVER P. JENKINS,
CHARLES H. GILBERT,
*Directors Hopkins Laboratory.*

Date of publication, October 31, 1898.

# PHYCOLOGICAL MEMOIRS.

BY DE ALTON SAUNDERS.

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## I.—SOME PACIFIC COAST ECTOCARPACEÆ.

## Family ECTOCARPACEÆ *C. Ag.*

*Ectocarpaceæ* C. AG., Syst. Alg., XXX, 1824. Emend. Thur. Le Jol. List. Alg. Mar. Cherb., 1863.

Plant body arising from a mass of creeping filaments or a disk-like mass of cells mostly monosiphonous, more or less branched; reproductive bodies of two kinds—plurilocular sporangia formed of numerous small, densely aggregated, linear, lanceolate, or ovoid cells; unilocular sporangia cuboidal or globose.

### SYNOPSIS OF GENERA.

The basal part of the plant consisting of branching filaments.
  The plurilocular sporangia intercalary with the cells of the vegetative filaments........................................ *Pylaiella.*
  The plurilocular sporangia not intercalary.
    Basal filaments mostly superficial..................... *Ectocarpus.*
    Basal filaments ramifying through the tissue of the infested plant *Streblonema.*
The basal part of the plant consisting of a cellular, disk-like mass.
  No paraphyses........................................ *Phycocelis.*

### 1. **Phycocelis** *Strœmf.*

*Phycocelis* STRŒMF., Not., III, 1888, 383.

Plant small epiphytic, the basal part consisting of one or two layers, more or less circular in outline, increasing by peripheral growth. Erect filaments present; unilocular sporangia and paraphyses unknown; plurilocular sporangia sessile or stout; zoosporal cells mostly erect in a single row.

Oct. 29, 1898.

### 2. **Phycocelis reptans** (*Crouan*) *Kjellm.*

PLATE XII, FIGS. 8–12.

*Phycocelis reptans* (CROUAN) KJELLM. Handbk. I, 1890, 81.
*Ectocarpus reptans* CROUAN, Fl. Finist., 161, 1867.

Plant forming rounded patches 1-5 mm. in diameter, the disk-like base of one or two layers of cells 12-15μ broad. Erect filaments 2-4 mm. high, unbranched, ending in an abrupt, hyaline hair; cells 8-12μ broad, as long to twice as long as the diameter; chromatophores small, oval or band form; plurilocular sporangia lanceolate or linear-oblong, sometimes curved, 25-75μ (commonly 40-55μ) x 12-30μ, terminal on the erect filaments or rarely sessile on the basal ones.

On the leaves and air-bladders of *Nereocystis lutkeanus.* Pacific Grove, California.

### 3. **Phycocelis fœcunda** *Strœmf.*

PLATE XII, FIGS. 1–7.

*Phycocelis fœcunda* STRŒMF., Not., 1888, 383.

Spots orbicular, ½ mm. or so broad. Creeping filaments united to form a disk-like, unistratose, basal part; the erect filaments simple, of 2-6 cells which become transformed into sessile or stipitate, uniseriate, cylindrical, plurilocular sporangia, 27-40μ x 6-10μ; a cluster of long hairs in the center of each spot.

On *Macrocystis pyrifera*, *Desmarestia ligulata*, and *Pterygophora Californica.* Pacific Grove, California.

### 4. **Streblonema** *Derb. & Sol.*

*Streblonema* DERB. & SOL., Cast. Cat. Pl. Mars. Suppl., 1851, 100.

Plant body filamentous, consisting of two parts, the numerous branching filaments ramifying through the tissue of a host plant; erect filaments branched or sessile, usually ending in or bearing long hairs; unilocular sporangia large, subglobose; plurilocular sporangia simple or sometimes branched, one to many seriate.

### 5. **Streblonema fasciculatum** (*Thur.*) *Le Jol.*

PLATE XIII.

*Streblonema fasciculatum* THUR. in LE JOL. Alg. mar. Cherb., No. 100, Liste p. 73.

Vegetative filaments irregularly much branched, branches alternate, irregular, 6-9μ broad, cells 1-3 times as long as broad, slightly constricted at the joints; unilocular sporangia globose or ovoid, sessile or rarely stalked, 25-35μ x 21-30μ, borne on the main filament or the branches; plurilocular sporangia lanceolate or linear, obtuse at the apex, sessile or stalked, borne on the branches near the surface of the infested plant, 40-100μ x 8-12μ, often uniseriate.

In *Nemalion andersonii* Farl. San Pedro, California, Aug., 1896.

The plant is composed of an irregularly branching mass of filaments running through the soft central filaments of the *Nemalion*. Some of the branches extend out to the surface and are simple; others are once or twice dichotomously branched near the surface. The plurilocular sporangia are very irregular, born singly or sometimes aggregated on the outer sides of the branches, not at all branched. Long and colorless hairs are born on the branches with the plurilocular sporangia.

### 6. **Ectocarpus** *Lyngb.*

*Ectocarpus* LYNGB., Hydrophyt. Dan., 1819, 130.

Plant filiform, branching, attached to the substratum by branching, creeping filaments. Erect filaments monosiphonous, branched, occasionally corticated by outgrowths of superficial cells; unilocular and plurilocular sporangia terminal or lateral, never intercalary.

### 7. **Ectocarpus acuminatus,** sp. nov.

PLATE XIV, FIGS. 1–5.

Plant minute; creeping filaments forming a compact network; erect filaments simple, of the same size from base to apex, a mm. or so high; cells not at all constricted, 12–14$\mu$ broad, below as long as the diameter, above 2–3–5 times as long; chromatophores elliptical, much more abundant in the central part of the filament; plurilocular sporangia sessile on the base of the erect filaments or arising on a long or short stalk from the creeping filaments, lanceolate, very long-acuminate, sometimes tipped with a short hair, often more or less curved, 90–300$\mu$ (rarely 400$\mu$) x 20–30$\mu$.

Forms minute, light brown tufts in the conceptacles of *Cystoseira osmundacea.* Pacific Grove, California, July, 1896; San Pedro, California, Aug., 1896.

The creeping filaments ramify through between the paraphyses and attach themselves to the inner wall of the conceptacle; the erect filaments extend out of the mouth of the conceptacle a mm. or so; the plurilocular sporangia point toward the opening or extend just out of it.

### 8. **Ectocarpus ellipticus,** sp. nov.

PLATE XIV, FIGS. 6–9.

Plant minute, erect, tufted, attached to the inner wall of the cryptostomata or conceptacles by a colorless mass of creeping, branching filaments. Erect filaments unbranched or with a few unicellular branches, 9–12μ broad; cells at base once to twice as long as the diameter, above three times as long; chromatophores oval, numerous; plurilocular sporangia linear or linear-lanceolate, 75–100μ x 18–25μ, borne laterally at or near the base of the erect filaments or occasionally arising directly from the creeping filaments, sessile, or the lower on short stalks; zoosporal cells 5–8μ broad, one to few seriate; unilocular sporangia sessile, ovate or elliptical, 30–40μ x 12–18μ, borne on the same tufts with the plurilocular sporangia.

Forming minute, dark brown tufts 1 mm. high in the cryptostomata and conceptacles of *Fucus evanescens*. Pacific Grove, California.

### 9. **Ectocarpus chitonicolus,** sp. nov.

PLATE XV, FIGS. 1–4.

Plant 1–2 mm. high; creeping filaments numerous, branched, 15μ broad; cells once to twice as long as the diameter; erect filaments mostly unbranched, 14μ broad at base, somewhat narrowed above; cells below ½–2 times as long as the diameter, above 2–3 times as long, not at all constricted at the joints; chromatophores numerous, small and oval; plurilocular sporangia lanceolate or narrowly ovate, obtuse at the apex, 90–175μ x 20–35μ, borne laterally in the erect filaments or occasionally on the creeping ones; the lower sporangia on a long or short stalk, the upper sessile.

Forms minute tufts on the back of a chiton. Pacific Grove, California.

A variable species which approaches *E. cylindricus* in some of its forms but is separated from it by the more pointed, plurilocular sporangia and the uniformly smaller size of the vegetative parts.

### 10. **Ectocarpus cylindricus,** sp. nov.

PLATE XVI.

Creeping filaments irregularly branched, 12–20μ broad; cells 2–3 times as long as the diameter; erect filaments simple or giving off a few short branches below, of the same size throughout, 18–30μ broad; cells below and above 2–3 times as long as the diameter, in the central part as long as the diameter, not at all constricted; chromatophores numerous, disk shaped; plurilocular sporangia lateral, on a one- to several-celled stalk, erect, cylindrical or obovate, very obtuse above, 80–200μ x 35–45μ, opposite, most abundant below; unilocular sporangia on separate filaments, ovate or elliptical, 60–120μ x 30–40μ, usually on a one-celled stalk, or the upper occasionally sessile, often opposite.

The plant forms a compact, velvety mass 2–4 mm. high, of indefinite extent on the stems and rhizoids of *Egregia* *menziesii*, on the fruiting tips of *Cystoseira osmundaceæ*, on rocks, on *Codium adhærans* and *C. mucronatum Californicum*. Pacific Grove, California, 1895.

The form on *Cystoseira* averages slightly larger and many of the plurilocular sporangia arise directly from the creeping filaments; no unilocular sporangia were found on this form. In the forms that grow on a hard substratum, the creeping filaments are short and form a compact network on the surface; in those that grow on a soft substratum (*Codium*, etc.) the creeping filaments are much elongated and ramify between the loose threads of the host plant.

### 11. **Ectocarpus hemisphericus**, sp. nov.

PLATE XVII.

Plant densely tufted, arising from a compact network of creeping filaments. Erect filaments unbranched at base, primary branches dichotomous, divergent, long, not at all narrowed upward, ending bluntly above, secondary branches numerous, short, clustered, many of them ending in a short, blunt hair; cells at base 15–20$\mu$ broad, 2–3 times as long as the diameter, above 22–30$\mu$ broad, 1–2 times as long as the diameter, slightly constricted at the joints; chromatophores small, numerous, linear or disk-shaped; plurilocular sporangia lanceolate or ovate, obtuse, short, 30–90$\mu$ x 14–20$\mu$ (rarely 30$\mu$ long), borne laterally on a short stalk in the upper part of the filament; unilocular sporangia short, cylindrical, 30–35$\mu$ x 20–25$\mu$, on a one-celled stalk, on the same filament with the plurilocular sporangia.

The plant is very abundant, forming dense, hemispherical tufts 2–4 mm. high on *Pelvetia fastigiata* and *Taonia lennebackeræ*. San Pedro, California, Aug., 1896.

But one specimen was found of the form on *T. lennebackeræ*.

### 12. **Ectocarpus hemisphericus minor**, form. nov.

PLATE XVIII, FIGS. 1–3.

Vegetative filaments simple or but slightly branched, 16–21$\mu$ broad.

The plant forms small, dark brown tufts 1–2 mm. high on the fruiting tips and upper branches of *Fucus harveyanus*. The whole plant is smaller and does not form the dense rounded tufts as in the type. San Pedro, California, Aug., 1896.

## 13. **Ectocarpus paradoxus pacificus,** var. nov.

PLATE XVIII, FIGS. 4-7.

Erect filaments arising from a compact mass of creeping ones, 25-40μ broad, divergently branched, branches long, bearing above several short, pointed branchlets; cells about as long as broad, near the extremities one-half as long, slightly constricted; plurilocular sporangia cylindrical, ovate or lanceolate, obtuse or abruptly pointed at the apex, borne laterally on the main stem and branches on a long or short stalk, 70-150μ x 25-50μ; unilocular sporangia on short stalk or intercalary, globose, about 30μ in diameter.

Forming small tufts 2-5 mm. high on *Fucus evanescens*, most abundant on the fruiting tips; differs from the type in its smaller size, in the branching which is never opposite, and in the plurilocular sporangia which are longer and more pointed.

## 14. **Ectocarpus mucronatus,** sp. nov.

PLATE XIX.

Plant light olive-green, attached at base by a few long, colorless, creeping filaments. Erect filaments 1-5-6 cm. high, loosely intertwined, terminated above by a short, colorless hair, unbranched at base; main filament 30-40μ broad; cells one-third to as long as the diameter, below three times as long, not at all constricted, branches spreading, numerous, scattered, mostly short and pointed; chromatophores disk-form, numerous in each cell; plurilocular sporangia sessile, numerous, 50-155μ x 20-30μ, ovate or lanceolate, short-acuminate, borne on both the main filament and the branches.

Attached to *Zonaria tournefortii* which was washed ashore. San Pedro, California.

Also on *Petrospongium berkleyi* collected on rocks near San Pedro by A. J. McClatchie (1273).

## 15. **Ectocarpus corticulatus,** sp. nov.

PLATE XX.

Plant erect, 3 mm. to 3 cm. and more high, arising from a small, compact network of creeping filaments. Main filament 90-120μ broad, irregularly much branched below, above somewhat dichotomously branched; branches 50-70μ wide, spreading, irregular, some long and bearing many short branches, others short and few celled, all ending abruptly; the main stem and the branches densely corticated; cells one-half to as long as broad, but slightly constricted; chromatophores few, large, band-form, each containing several pyrenoids; plurilocular sporangia very variable in size and shape, lanceolate or narrowly ovate, short stalked or sessile, mostly 30-40μ x 12-18μ (occasionally 50–70μ x 20–30μ), most abundant on the upper side of the ultimate branches but found also along the main stem and primary branches, below apparently arising from the corticating filaments.

Forming small, loose masses, 2 mm. to 5 or 6 cm. high, on *Desmarestia ligulata*, Monterey; on *Zostera* leaves with *E. granulosus*. San Pedro, California.

### 16. **Ectocarpus mitchellæ** *Harv.*

Plate XXI, Figs. 1 and 2.

*Ectocarpus mitchellæ* Harv., Ner. Bor.-Amer., I, 1851, 143.
*Ectocarpus indicus* Sond., Zoll. Verz. Ind. Arch. ges. pflanz., 3, 1854.

Plant arising from long, creeping filaments 10–15μ wide; cells 5–10 times as long as the diameter. Erect filaments unbranched below, bearing above many alternate branches which have numerous short, spreading branchlets; branches and branchlets pointed or ending in a short hair; main filament 25–40μ wide, 1–3 times as long as the diameter; chromatophores numerous, small, disk-form; plurilocular sporangia cylindrical, obtuse, 50–100μ x 18–35μ, sessile, mostly secund on the upper side of the branches.

Forming light olive-green tufts 1–2 cm. high on rocks at the low tide level. San Pedro, California.

A careful study of the plant showed it to be identical with the figures and description of *E. indicus* given by Askenasy in Ein. Austr. Meersalg., 8, 1894. The same plant was received from Prof. McClatchie named *E. mitchellæ*. From a careful comparison of the plates and descriptions of *E. indicus* and *E. mitchellæ*, the two species seem to be identical. Mr. F. S. Collins has received the same plant from San Diego, where it has been called *E. virescens* Thuret. He has "no doubt that Harvey's and Thuret's species are the same."

### 17. **Ectocarpus siliculosus parvus,** var. nov.

Plate XXII.

Plants tufted, erect, 1–2 cm. high; primary branches numerous, alternate, gradually contracted above into long hyaline hairs, bearing many short, pointed branches. Cells with the main filament 21–30μ broad, 1–3 times as long, slightly constricted at the joints; plurilocular sporangia narrowly lanceolate or conical, 120–290μ x 20–27μ, pointed and often tipped with a long hair, borne on a long or short stalk, abundant on the main filament and the primary branches; unilocular sporangia ovate or elliptical, usually sessile, 35-55μ x 20-27μ, sometimes on the same filament with the plurilocular sporangia.

Forming a yellow fleece on sand-colored rocks. San Pedro, California, 1895. Collected by W. A. Setchell (1213).

The Pacific plant differs from the type and from the form *hiemalis* in the smaller size of the vegetative parts and the plurilocular sporangia; from the form *arctus* (Kuetz.) Kuck. in the much narrower vegetative filaments and larger plurilocular sporangia.

### 18. **Ectocarpus confervoides** (*Roth*) *Le Jol.*

*Ectocarpus confervoides* (ROTH) LE JOL., List. Alg. Mar. Cherb., 75, 1880.

Plants 2 cm. to 3 or 4 dcm. long, attached to the substratum by horizontal creeping filaments, often entangled at the base; branches alternate, gradually tapering, often corticated, cells of the larger branches 35-50μ broad, as long to one-half as long as the diameter; plurilocular sporangia narrowly lanceolate and subulate to ovate and acute, sessile to short or long stalked; unilocular sporangia ovate, globose, or elliptical.

Of this variable, cosmopolitan species two forms have been collected on the Pacific coast.

### 19. **Ectocarpus confervoides pygmæus** (*Aresch.*) *Kjellm.*

PLATE XV, FIGS. 5-9.

*Ectocarpus confervoides pygmæus* (ARESCH.) KJELLM., Handbk. I, 1890, 76.

Erect filaments arising from a compact substratum of short creeping filaments, unbranched or bearing above a few divergent, long branches, in figures 12-25μ in diameter, not at all narrowed above; cells at base 2-3 times as long as the diameter, above once to one-half as long; chromatophores large, irregular, band-form, few in each cell; plurilocular sporangia lateral and terminal, sessile or short stalked, lanceolate or conical, rather obtuse at the apex, 60-100μ x 20-30μ; unilocular sporangia lateral, abundant, ovate or globose, 25-40μ broad, often two to many seriate.

Forming an olive-brown, velvety covering on *Desmarestia ligulata* and *Dictyoneuron Californicum*. Pacific Grove, California.

## 20. **Ectocarpus confervoides variabilis,** form. nov.

PLATE XXIII.

Plant 2-8 mm. high, sparingly branched, branches alternate, distant, long drawn out at the tip, cells 10–30μ broad, 1–3 times as long as the diameter, not at all constricted; chromatophores large, band-form, few in each cell; plurilocular sporangia abundant, lanceolate, fusiform or narrowly ovate, usually on a one- to few-celled stalk, borne laterally on the main stem or branches, occasionally arising by a short stalk from the creeping filaments; 75–90μ x 16–35μ; unilocular sporangia globose or ovate, 15–35μ wide, single or 2–15 seriate, borne on a one- to three-celled stalk, mostly on the same filament with the plurilocular sporangia but much less common.

Forming light olive-brown tufts on *Laminaria andersonii, Iridæa laminarioides, Macrocystis pyrifera, Egregia menziesii, Nemalion multifidum, Alaria esculenta,* and *Lessonia littoralis.*

A very common species and one that varies considerably in the size of the vegetative filament and the plurilocular sporangia.

## 21. **Ectocarpus penicillatus** *C. Ag.*

PLATE XXI, FIGS. 3 AND 4.

*Ectocarpus penicillatus* C. AG., Syst. Alg., 1824, 162.

Plant densely tufted, dark olive-green, 1–4 cm. high; main stem and few of the primary branches corticated; cells of the primary branches 20–35μ broad, a little shorter than the diameter; secondary branches somewhat secund, short and very numerous; plurilocular sporangia linear or linear-lanceolate, sessile pedicillate, acute 85–165μ x 12–20μ, borne mostly on the secondary branches.

A dark, olive-green plant forming dense tufts on *Desmarestia ligulata.* Pacific Grove, California.

## 22. **Ectocarpus tomentosus** (*Huds.*) *Lyngb.*

PLATE XXIV, FIGS. 1 AND 2.

*Ectocarpus tomentosus* (HUDS.) LYNGB., Hydrophyt. Dan., 1819, 132.

Plants forming tufts 1–4 cm. long, of densely interwoven, irregularly, much branched filaments forming a rope-like spungy mass. Filaments 6–8μ wide; cells 2–4 times as long as the diameter; branches long, divergent, the ultimate ones standing at right angles, curved at the tip; chromatophores large, irregular, band-form, few; plurilocular sporangia linear-oblong, 40–110μ x 12–18μ, given out at right angles to the filament, sessile or occasionally short-pedicillate, often curved; "[1] sporangia almost elliptical, on short pedicels."

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[1] Hauck in Rab. Crypt. Fl. Vol., II, 330.

Common on *Fucus evanescens* and *Fucus harveyanus.* Monterey, California.

One of the commonest Pacific coast species; where it occurs in large quantities it appears to be very destructive to the "host" plant. The tufts average much smaller than those of the Atlantic coast specimens.

### 23. Ectocarpus granulosus (*Engl. Bot.*) *Ag.*

PLATE XXIV, FIGS. 3-5.

*Ectocarpus granulosus* (ENGL. BOT.), AG., Sp. Alg. II, 1828. 45.

Filaments 1-8 cm. high; main branches mostly opposite, many of them corticated, cells 40-75$\mu$ broad, one-half to as long as the diameter, secondary branches opposite, short, given off at wide angles, curved at the tips; ultimate branches secund, short and acute; plurilocular sporangia abundant, sessile on the secondary and ultimate branches, broadly ovate, obliquely truncate at the base, 60-100$\mu$ x 30 to 60$\mu$; unilocular sporangia wanting.

On rocks, *Costaria mertensii*, and *Nereocystis lütkeanus*, Pacific Grove, California; and on *Zostera marina*, San Pedro, California.

The Californian plant agrees with Dr. Farlow's variety *tenuis* in the size and branching of the vegetative filaments, but has the plurilocular sporangia of the type.

### 24. Pylaiella *Bory.*

*Pylaiella* BORY, Dict. Class. IV, 1825, 393.

Plant filiform, monosiphonous, more or less branched, attached to the substratum by more or less branched creeping filaments. Unilocular sporangia globose, seriate, arising from the transformation of a part of the vegetative cells of any of the branches, opening laterally; plurilocular sporangia oblong or cylindrical, intercalary, opening laterally, or occasionally terminal and opening at the apex, single or many seriate.

### 25. Pylaiella littoralis densa, form. nov.

PLATE XXV, FIGS. 1 AND 2, 5 AND 6.

Vegetative filaments below densely intertwined into rope-like masses, penicillate above, branched. Branches numerous, long, opposite or alternate, bearing many short branchlets; main filament and branches 18-25$\mu$, cells 1-3 times as long as the diameter, not at all constricted; unilocular sporangia globose, 2-15 in a series, most abundant in the branches and branchlets, 21-30$\mu$ in diameter; plurilocular sporangia scarce, mostly in the main filament, 20-50$\mu$ x 20-30$\mu$, 2-10 or more in a chain.

The plant forms dense, ropey, dark olive-brown masses 3–8 cm. long on *Fucus* sp. Ilwaco, Washingion, near the mouth of the Columbia River.

On the southern Californian coast material was collected of what seems to be another well marked variety of *P. littoralis.* As the material was sterile I forbear making any further additions to the long list of varieties and forms of this species.

The description of the plant is given below:—

### 26. **Pylaiella littoralis,** var.

PLATE XXV, FIGS. 3 AND 4.

Plant composed of loosely intertwined, light olive-green filaments of indefinite length, bearing a few long attentuate branches 20-70μ broad, ½–2 times as long as the diameter, not at all narrowed upwards. Main filament and the branches bearing many one- to few-celled branchlets which stand at right angles to the filament.

Forming a light yellow flocculent mass of a few cm. long on *Amphiroa.* San Pedro, California, Aug., 1896.

## II.—SPHACELARIACEÆ AND ENCŒLIACEÆ OF THE PACIFIC COAST.

### Family SPHACELARIACEÆ (*Decne.*) *Kuetz.*

*Sphacelariaceæ* (DECNE.) KUETZ., Linn., XVII, 1843, 93.

Plant body arising from a larger or smaller mass of cellular tissue, polysiphonous, more or less branched, increasing by the division of a large terminal cell; reproductive organs (unilocular and a plurilocular sporangia) arising on a longer or shorter stalk directly from the basal tissue or borne laterally on the erect filaments.

The family includes at present about eleven genera, only one of which has been collected on the California coast.

### 27. **Sphacelaria** *Lyngb.*

*Sphacelaria* LYNGB., Hydrophyt. Dan., 103, 1819.

Plant olive-brown, tufted, filamentous, branching; basal plate fastened to rocks or in the tissue of other algæ as a substratum; both the axis and branches terminated by a large apical cell which by transverse, longitudinal, and oblique division produces a plant body, the external surface of which is composed of rectangular cells arranged in regular, transverse bands. Unilocular and plurilocular sporangia mostly extra-axillary on the branches, on a one- to few-celled stalk; propagula known in most species, on separate plants.

### 28. **Sphacelaria tribuloides** *Menegh.*

PLATE XXVI.

*Sphacelaria tribuloides* MENEGH., Lett. al Corinaldi 2, N. 1; Alg. Ital., 336, 1842.

Plant densely tufted, olive-brown; primary branches somewhat dichotomous, appressed, bearing above numerous alternate or opposite branches. Main filament composed of 4-8 siphons, 50-70$\mu$ wide, the external cells 1-½ as long as the diameter of the filament; propagula obcordate on the upper branches; plurilocular sporangia elliptical or obovate, 75-150$\mu$ x 50-70$\mu$, on a one- to four-celled stalk.

The plant forms dense tufts 1-3 or 4 cm. high, on rocks at the low tide line. Collected by Prof. A. J. McClatchie.

### **Sphacelaria didichotoma,** sp. nov.

PLATE XXVII.

Plant forming small, cushion-like masses 2-4 mm. high. Erect filaments arising from a small compact substratum, bearing many long, spreading, alternate branches; main filament 25-35$\mu$ broad; external cells ½ to as long as the diameter of the filament; axis of the filament of four or five siphons; propagula abundant, large, twice dichotomus, often standing at right angles to the main filament; stalk 2-300$\mu$ long, main branches 100-200$\mu$. long.

Forming small, compact tufts on *Melobesia* and *Ahnfeldtia.* Carmelo Bay, California.

## Family ENCŒLIACEÆ (*Kuetz.*) *Kjellm.*

*Encœliaceæ* (KUETZ.) KJELLM., Phyc. Gener., 336, 1843.

Reproductive organs developed from superficial cells or from one of the divisions of a superficial cell; plant tissue of parenchymatous structure; growth intercalary, growing point near the base.

SYNOPSIS OF GENERA.

Plant body undifferentiated—of similar structure throughout.
  Plant thin, a flat, leaf-like membrane.................. *Homeostroma.*
Plant body differentiated—composed of at least two kinds of cells.
  Sporangia sunken beneath the surface, plant hollow, cylindrical, or club shaped........................................ *Coilodesme*
  Sporangia on the surface.
    Paraphyses none, plant a leaf-like membrane.
      Central layer of tissue composed of large, irregularly rounded cells........................................ *Phyllitis.*
      Central layer of tissue a loose web of slender branching filaments...................................... *Endarachne.*
      Central layer of tissue composed of a smaller, compact layer of cells reproducing by unilocular sporangia...... *Halorhipis.*
    Paraphyses unicellular.
      Plant body hollow, cylindrical.................... *Scytosiphon.*
      Plant body hollow, irregulary rounded or oval..... *Colpomenia.*
    Paraphyses multicellular; plant body rounded or oval, plants mostly aggregated...................................... *Soranthera.*

## 30. **Homeostroma** *J. Ag.*

*Homeostroma* J. AG., Anal. Alg. Cont., III, 1896, 3.
*Punctaria* GREV., Syn. in Alg. Brit., XLII, 1830, (in parte.)

Plant body membranaceous, of several (2–7) similar layers of cuboidal cells. Unilocular and plurilocular sporangia oblong or oval, formed from the outer layer of cells; paraphyses none, furnished with numerous clusters of hairs.

## 31. **Homeostroma latifolium** *J. Ag.*

PLATE XXX, FIGS. 4 AND 5.

*Homeostroma latifolium* J. AG., l. c.
*Punctaria latifolia*, Born. et Thur., Étud., phycol. p. 13.

Plant body arising from a minute disk, lanceolate-obovate, 1–5 dcm. long, tapering below to a short stalk 2–10 mm. long, olive-green, plaited on the edges; tissue consisting of 4 or 5 rows of cells; unilocular and plurilocular sporangia scattered, on the same plant.

Attached to leaves of *Zostera marina* washed ashore at Monterey, California.

## 32. **Coilodesme** *Strœmf.*

*Coilodesme* STRŒMF., Eing. Meersalg. Isl., 173, 1886.

Plant body hollow, cylindrical or oval, on a short, solid stalk which arises from a minute disk-like base composed of two (or three) layers of tissue, an inner layer of large, mostly colorless, cylindrical cells and an outer layer of smaller colored cells. Unilocular sporangia solitary, scattered, developed from the outer layer of cells but surrounded by the continued growth of the outer layer of tissue; plurilocular sporangia, hairs, and paraphyses wanting.

## 33. **Coilodesme californica** (*Rupr.*) *Kjellm.*

PLATE XXIX, FIGS. 1–3.

*Coilodesme californica* (RUPR.) KJELLM. in Engl. and Prantl. Natürl. Pflanzenfam., Lief. 86, 202, 1893.

*Adenocystis californica* RUPR., Tange. Ochot, 29.

Plant olive-green, hollow, inflated, thin membranaceous or papery, cylindrical or ovoid, 2–6 dcm. long, ½–1 dcm. wide, abruptly contracted below into a short, solid stalk 1–3 mm. long. Sporangia abundant, scattered over the whole surface of the plant, ovate, 25–30$\mu$ x 12–15$\mu$.

Abundant on the upper branches of *Cystoseira osmundacea*. Pacific Grove and San Pedro, California.

The plants appear in June as minute, smooth, air-tight sacks filled with a gelatinous liquid which is formed from the degeneration of the central tissue. They gradually increase in size, soon becoming wrinkled and folded and finally torn, especially at the ends. The walls are thin and delicate and are composed of two layers of poorly differentiated tissue. The single outer row of cells is rounded and though not well developed it is easily distinguished from the hypodermal layer. The hypodermal layer is composed of two or three layers of irregularly rounded or quadrangular cells; beneath this is the central layer composed of three or four layers of large cylindrical cells surrounded by many smaller ones. The hypodermal layer is supplied with one or two large oval chromatophores, and occasionally one is found in the central layer of tissue.

## 34. **Halorhipis**[1], gen. nov.

PLATE XXVIII.

Plant body solid, leaf-like, arising from a disk-like base, composed of two layers of tissue, the outer layer consisting of 2–3 rows of cuboidal cells, the inner layer of several rows of large, cylindrical cells; reproducing by unilocular sporangia collected in sori which are distributed over the whole surface of the plant; hairs numerous, forming the center of the sori; plurilocular sporangia and paraphyses wanting.

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[1] ἅλς=sea, ῥιπίς=fan.

### 35. **Halorhipis winstonii** (*Ands.*)

PLATE XXVIII.

*Punctaria winstonii* ANDS., Some New and Old Algæ, Zoe IV, 1896, 358.

Plant membranaceous, olive-brown, lanceolate, obovate, or spatulate, 8 cm.-2 dcm. long, 2-5 cm. broad, usually frayed and torn at the end, gradually narrowed below into a short stalk (2-8 mm. long). Unilocular sporangia elliptical, obovate, or pyriform, 30-45μ x 20-30μ, sori numerous, forming irregular, linear patches of various sizes.

On *Egregia menziesii* and on rocks at low tide level. Carmelo Bay, California.

In 1895 a study was made of material received from Dr. Anderson, and the distinctness of this plant from *Punctaria* was at once noticed. During the summer of 1896 several trips were made to Carmelo Bay, fresh material in all stages of growth was obtained from the same locality where the type specimens were collected by Mr. Winston and sent to Dr. Anderson.

### 36. **Phyllitis** *Kuetz.*

*Phyllitis* KUETZ., Phyc. Gener., 342, 1843.

Plant body solid, membranaceous, lanceolate or linear, tapering toward the base to a short round stem, of two layers of tissue, the cortical layer of small cuboidal cells, the inner layer of oblong colorless cells. Unilocular sporangia linear, covering the entire surface of the plant; plurilocular sporangia and paraphyses wanting.

### 37. **Phyllitis fascia** (*Muell.*) *Kuetz.*

PLATE XXX, FIGS. 1-3.

*Phyllitis fascia* (MUELL.) KUETZ., l. c.
*Fucus fascia* OEDER, Fl. Dan. Tav., 768, 1761.

Plant single or clustered, arising from a disk-like base, 2-30 cm. high, 1-5 cm. broad, linear, lanceolate, or elliptical, narrowed at base into a short stem, or sessile.

Two forms of this variable species have been collected on the Californian coast:

*A.*—Plants gregarious, linear or oblanceolate, 3-15 cm. long, 3 mm. to 1 cm. wide, gradually narrowed to a short stalk.

On rocks and *Phyllospadix* sp. Monterey and Pacific Grove, California.

*B.*—Plants single or somewhat clustered, broadly lanceolate, plaited on the margin, 5–9 cm. long, 1-2 cm. broad, basal stalk very short or none. San Pedro and Pacific Grove, California.

In external appearance this form is almost undistinguishable from *Endarachne.*

## 38. Endarachne *J. Ag.*

*Endarachne* J. AG., Anal. Alg. Cont., III, 1896, 26.

Plant plain, simple, without a rib, composed of three layers of tissue; the axillary tissue of slender, intertwined, articulate filaments, on each side of this a single row of slightly coherent hypodermal cells, outside of which there is a double layer of small cells, slightly elongated in a longitudinal direction; reproducing by plurilocular sporangia scattered over the whole surface of the plant.

## 39. Endarachne binghamiæ *J. Ag.*

PLATE XXX, FIGS. 6 AND 7.

*Endarachne binghamiæ* J. AG., l. c., 27.

Plant clustered, smooth, olive-brown, 5 cm. to a dcm. or so high, 1-2 cm. broad, obtuse above, tapering below to a very short stalk.

A single dried specimen of this plant, collected at San Pedro, California, was received from Prof. McClatchie about the time of the publication of Agardh's description; figure 7 was drawn before the publication was received. In external appearance the plant is almost undistinguishable from the broader form of *Phyllitis fascia;* it is, perhaps, a little thinner and more abruptly contracted at the base. Agardh places it between *Scytosiphon* and *Phyllitis.* It has been suggested that perhaps all that has been called *Phyllitis* on this coast is really *Endarachne.* A study of many specimens from Monterey and San Pedro seems to show that *Phyllitis* is quite abundant and *Endarachne* is found, so far at least, only on the Southern coast.

## 40. Scytosiphon *Ag.*

*Scytosiphon* AG., Sp. Alg., I, 1823, 160.

Plant body filiform when young, tubular when mature, composed of two layers of tissue, the outer of small quadrangular cells, the inner layer of thick-walled, vertically elongated, colorless cells. Plurilocular sporangia developed from the cortical layer of cells, covering the whole surface of the plant; paraphyses single celled, oblong-ovate, sometimes wanting.

## 41. **Scytosiphon lomentarius** (*Lyngb.*) *J. Ag.*

PLATE XXXI, FIGS. 8-10.

*Scytosiphon lomentarius* (LYNGB.), J. AG., l. c., 126.
*Chorda lomentaria* LYNGB., Hydrophyt. Dan., 74, 1819.

Plant body unbranched, tubular, arising from short (1 cm. long) filiform stalks, 1-4 dm. long, 1-10 mm. thick; constrictions regular and frequent, occurring at long intervals or entirely wanting.

On rocks, Pacific Grove, Monterey, Santa Cruz, San Pedro and San Diego, California (Averill's set).

One form found mostly below the low tide line is broad and short and the constrictions are regular and frequent; another form occurring on overhanging rocks at or above the high tide line approaches the variety *complanatus* of Rosenvinge. It is longer and more slender than the preceding form and the constrictions are seldom present. Between these two there is such an imperceptible gradation that it is difficult to draw a line of separation.

## 42. **Scytosiphon bullosus,** sp. nov.

PLATE XXXI, FIGS. 1-7.

Plant erect, membranaceous, hollow, dark olive-green, cylindrical to broadly ovate, 1-5 cm. high, 1-2 cm. broad, simple or lobed above, narrowed at base into a broad disk-like attachment; surface at first smooth, wrinkled, and often torn with age. Plurilocular sporangia, paraphyses, and hairs undistinguishable from those of *S. lomentarius.*

On rocks, exposed at low tide with *Leathesia* and *Ulva.* Pacific Grove, California, Aug., 1896.

A very variable species but apparently quite distinct from *S. lomentarius.*

## 43. **Colpomenia** *Derb. & Sol.*

*Colpomenia* DERB. & SOL., Phys. Alg., p. 11, 1856.

Plant body globose or oval, hollow, the walls entire or irregularly torn, composed of two layers of tissue; the inner layer consisting of a few large, rounded, colorless cells, the outer of small quadrangular colored cells. Plurilocular sporangia at first forming sori around the hairs, soon spreading over the whole surface of the plant, interspersed with unilocular, clavate, paraphyses.

### 44. Colpomenia sinuosa (*Roth*) *Derb. & Sol.*

PLATE XXXII, FIGS. 7 AND 8.

*Colpomenia sinuosa* (ROTH) DERB. & SOL., l. c.
*Ulva sinuosa* ROTH, Cat. Bot., III, 327, Tab. 12, 1806.
*Asperococcus sinuosus* BORY, of Anderson's list, etc.

Plant body sessile, thin, membranaceous, 4 cm. to a dcm. high, sunken and occasionally irregularly torn in the older forms, tissue .255 mm. in thickness, the outer row of cells consisting of one or two rows of cuboidal, colored cells, inner layer of two rows of large roundish cells; plurilocular sporangia 20 x 7μ, often containing the zoospores cells in two rows; paraphyses a little shorter and broader, 17 x 10μ.

The plant is usually found attached to other seaweeds and seems to prefer quiet coves. Carmelo Bay, Monterey Bay, and San Pedro, California.

### 45. Colpomenia sinuosa expansa, form. nov.

PLATE XXXII, FIGS. 4-6.

Plants aggregated, forming an indefinite expanded mass on rocks; plant tissue .425 mm. in thickness, the inner layer of tissue being composed of 5-7 rows of cells.

Santa Catalina Island near Avalon Bay, California.

### 46. Colpomenia tuberculata, sp. nov.

PLATE XXXII, FIGS. 1-3.

Plant coriaceous, olive-brown, sessile, hollow, hemispherical, 5 cm. to a dcm. or more in diameter; surface deeply convoluted, wrinkled, and folded, the whole surface covered in the mature plant with blunt tubercles 1 mm.-10 mm. high, 1-5 mm. broad. Plurilocular sporangia 22-25μ x 3-4μ, composed of 6-8 zoosporal cells in a single row; paraphyses 22 x 5μ, remaining after the zoospores have escaped.

Near San Pedro, California.

The plant forms large rounded brain-like masses attached to rocks by the whole under surface; the outer layer of tissue .65-.80 mm. in thickness, composed of 3-5 layers of cuboidal cells, the inner 5-8 rows of large irregular cells. The plant tissue is of firmer texture and much thicker than in *C. sinuosa*. The structure of the tissue is very similar to that of *Hydroclathrus cancellatus*.

## 47. **Soranthera** *Post. & Rupr.*

*Soranthera* Post. & Rupr., Illustr. Alg., 19, 1840.

Plant body hollow, inflated, composed of two layers of tissue, with a cortical layer of small, colorless cells, the inner of large, nearly colorless cells. Unilocular sporangia forming sori which are distributed over the entire surface of the plant; paraphyses unicellular, hairs abundant in the center of each sori; plurilocular sporangia unknown.

## 48. **Soranthera ulvoidea** *Post. & Rupr.*

Plate XXIX, Figs. 4 and 5.

*Soranthera ulvoidea* Post. & Rupr., l. c.

Plants gregarious, sessile, membranaceous, olive-green, globose or oval, 2–8 or 10 cm. high. Sori very abundant, evenly and closely distributed over the whole surface of the plant. Unilocular sporangia clavate, 70–100$\mu$ long, surrounded by numerous linear paraphyses which are nearly twice as long.

In sheltered coves, usually on *Rhodomela larix*, occasionally on rocks and other algæ. Monterey, California.

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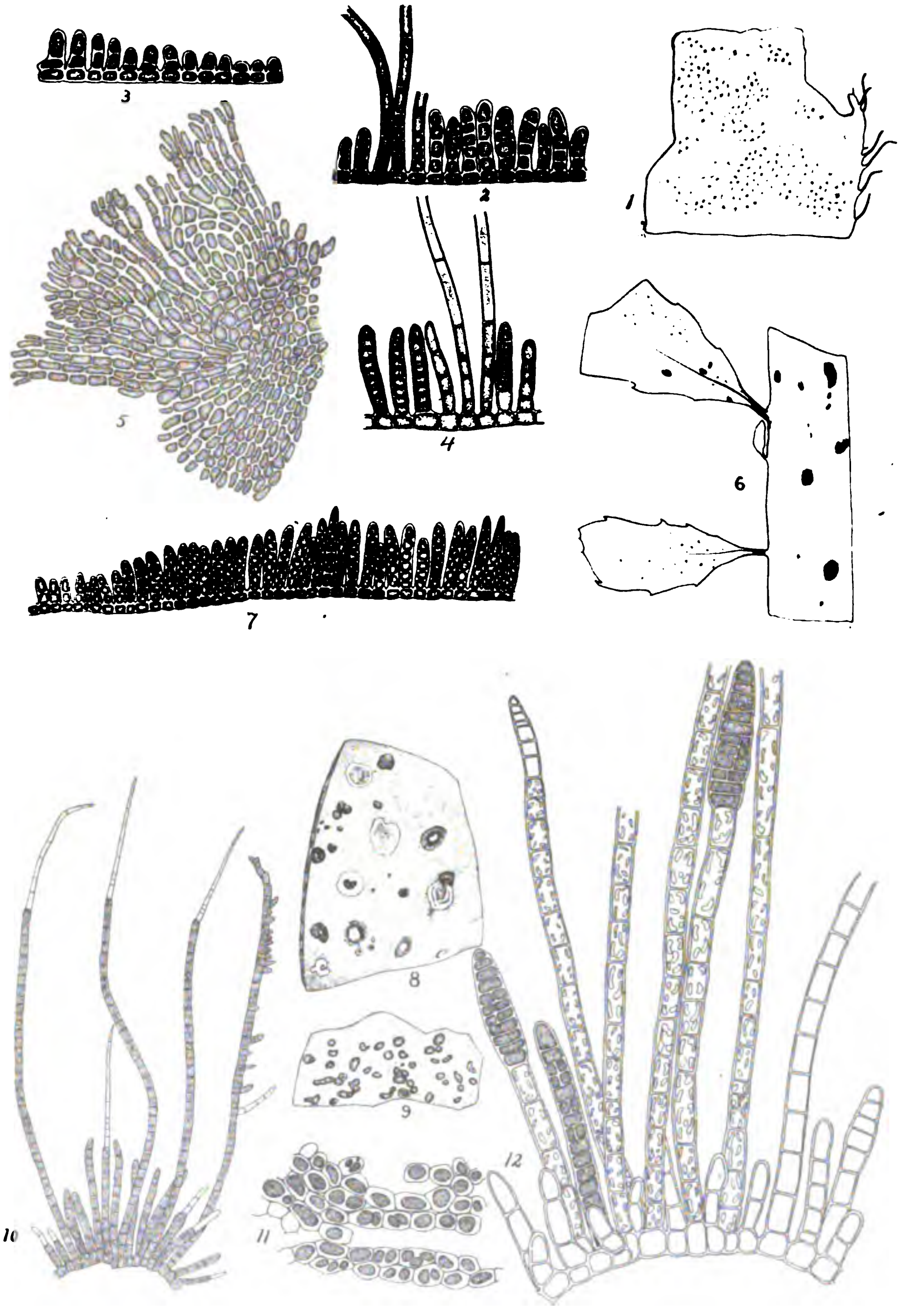

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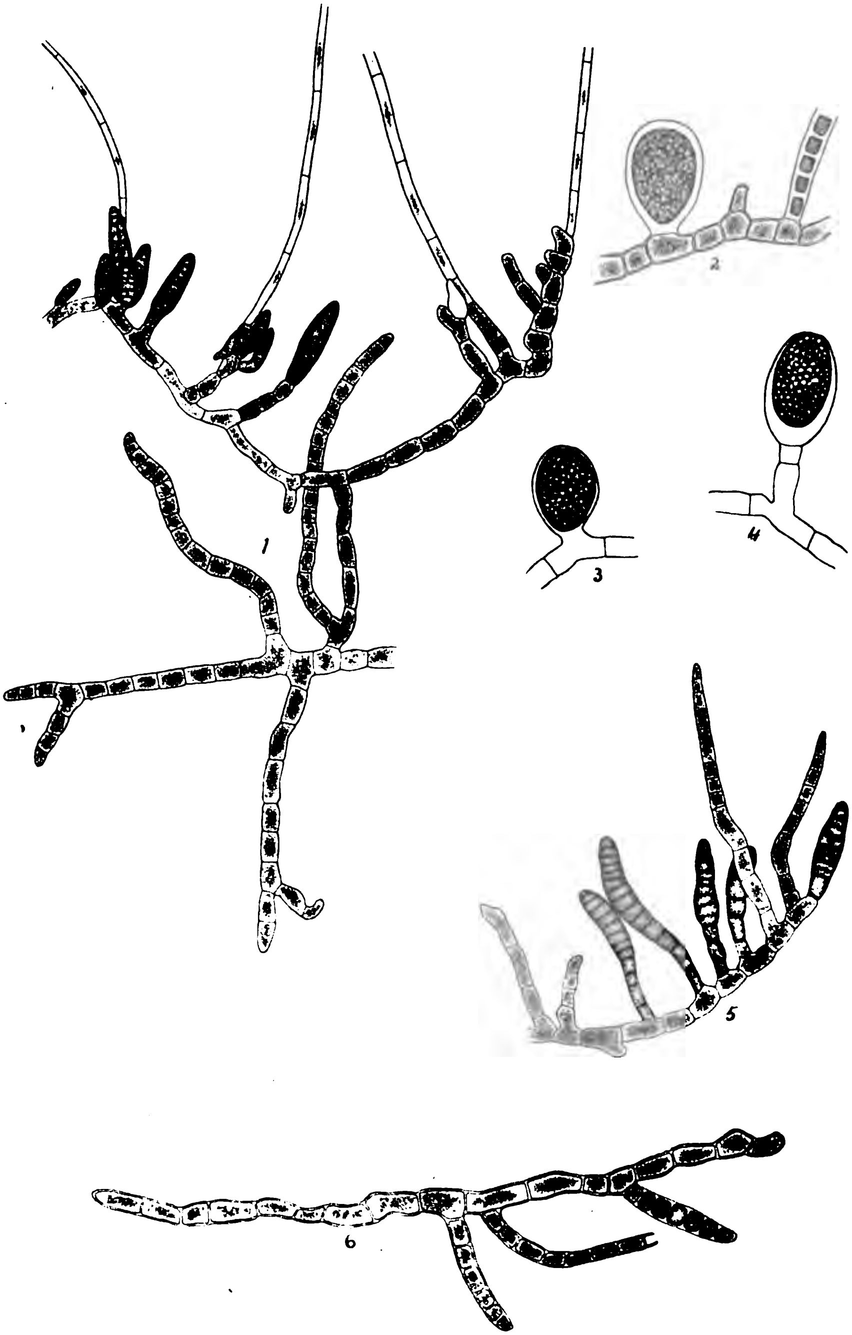
FIGS. 1-7 PHYCOCELIS [illegible] SAUNDERS
FIGS. 8-12 PHYCOCELIS REPTANS [illegible]



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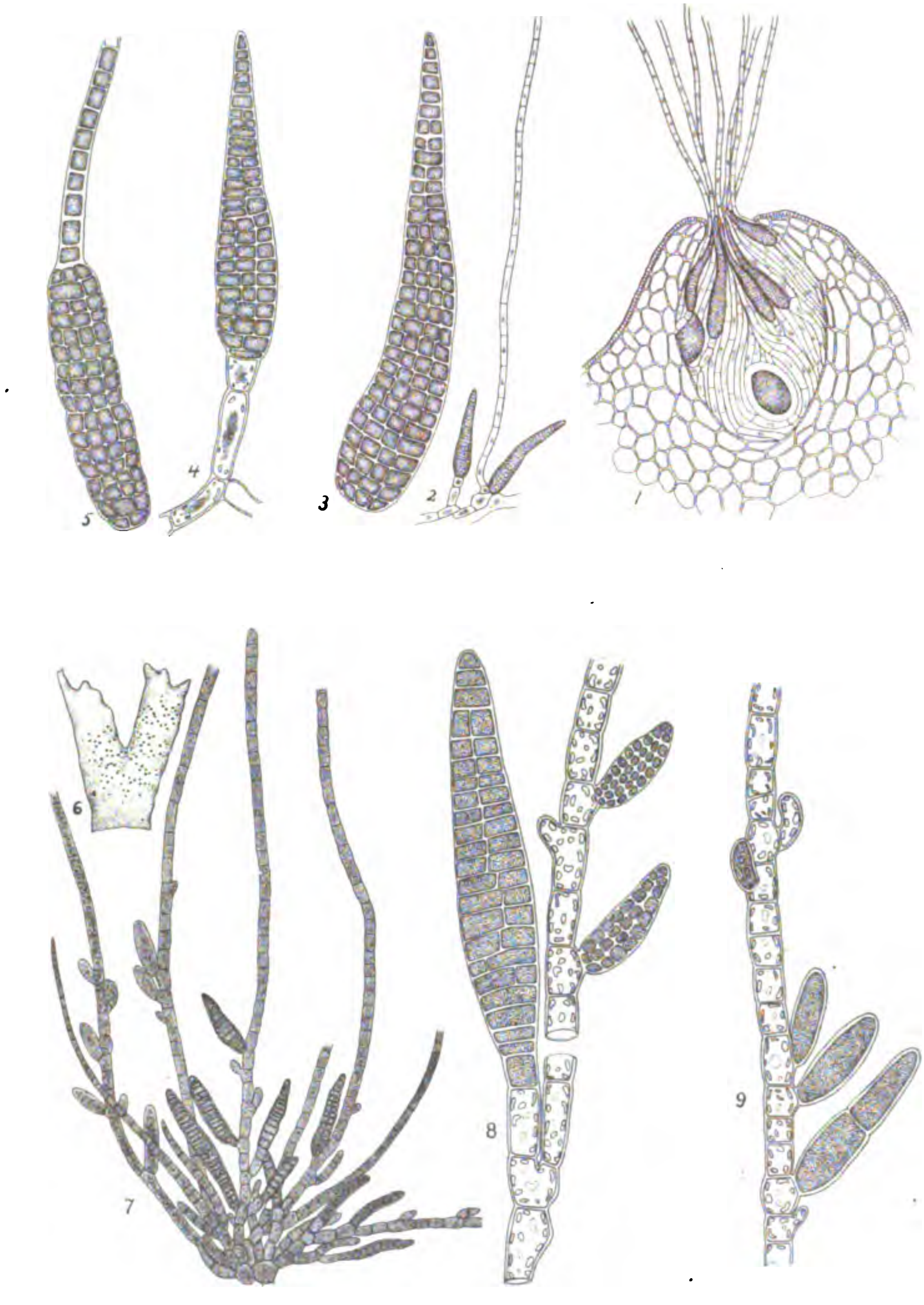

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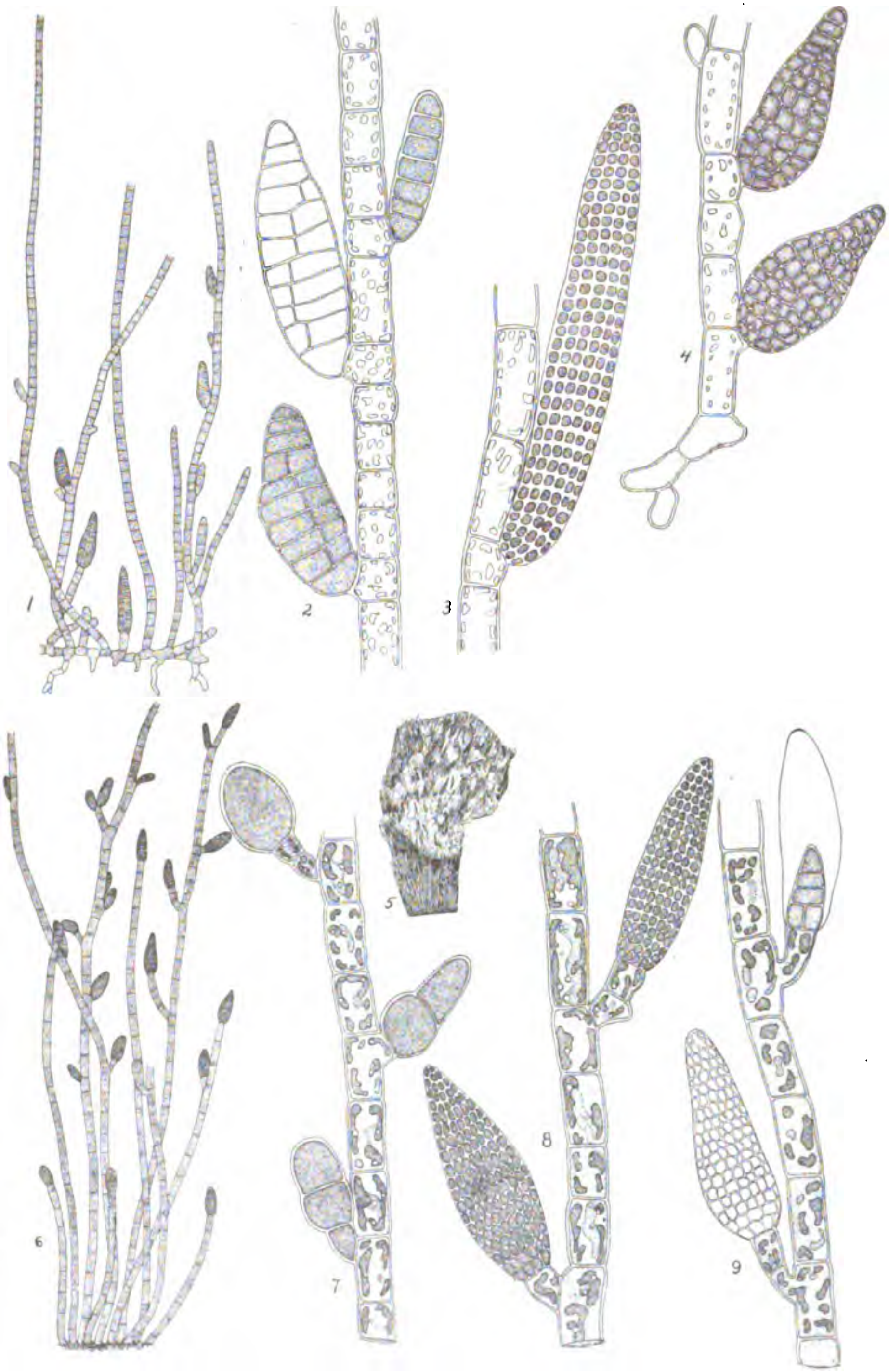
FIGS 1 - 5 ECTOCARPUS ACUMINATUS, SP NOV

FIGS 6 - 9 ECTOCARPUS ELLIPTICUS, SP NOV



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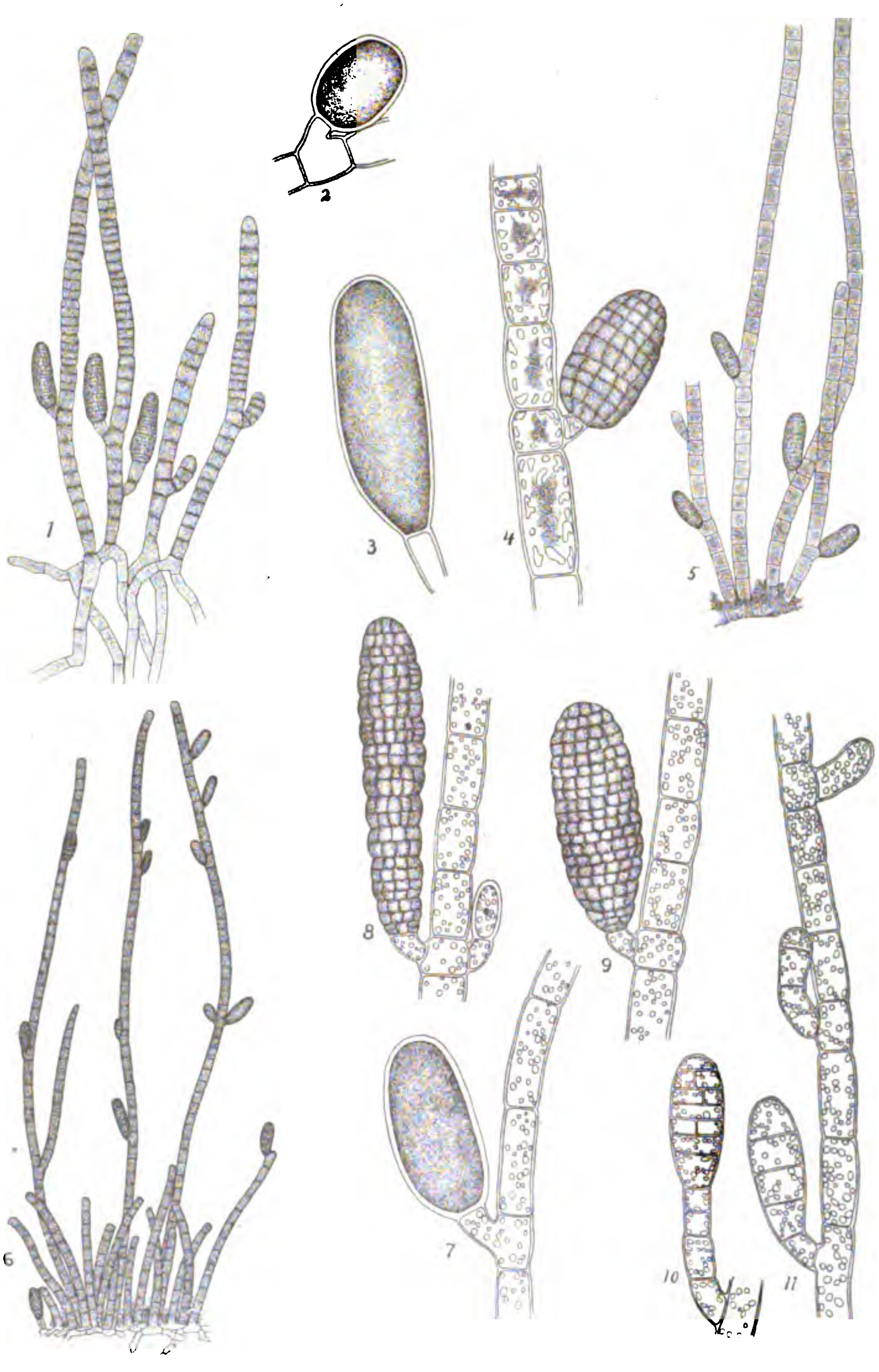
FIGS. 1–4 [illegible], SP. NOV.

FIGS. 5–9 [illegible]



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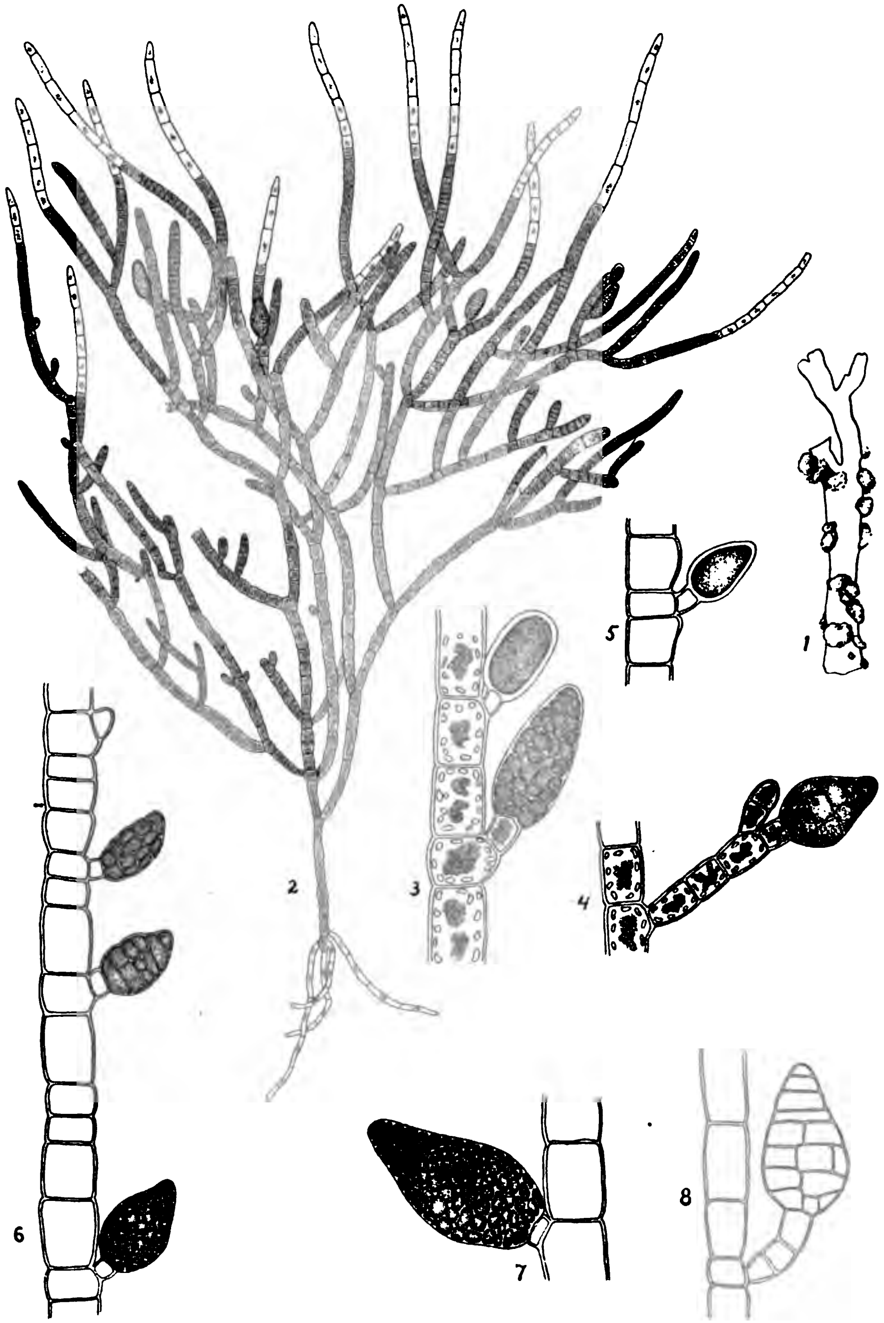
ECTOCARPUS CYLINDRICUS SP. NOV.



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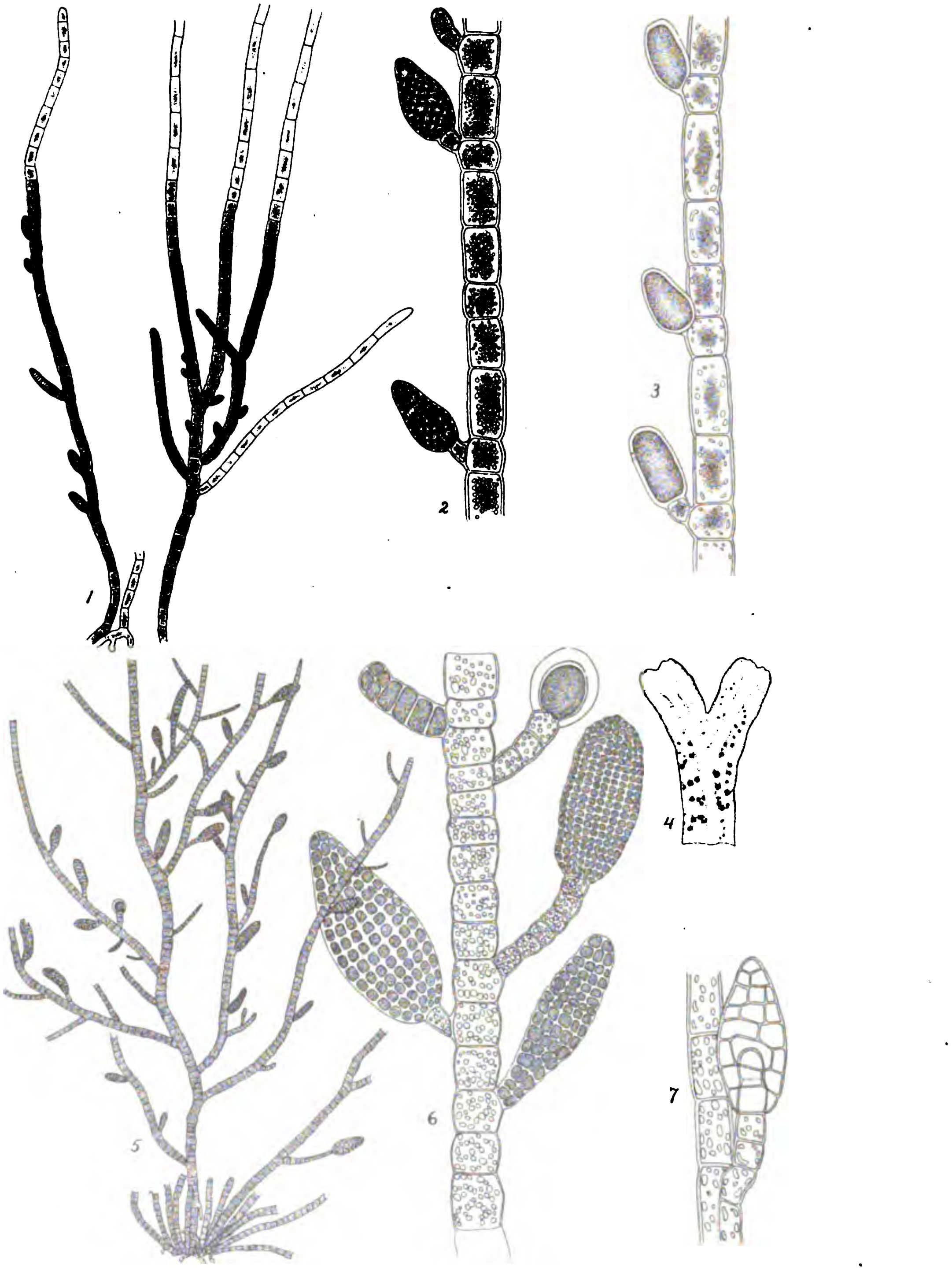
ECTOCARPUS [illegible]



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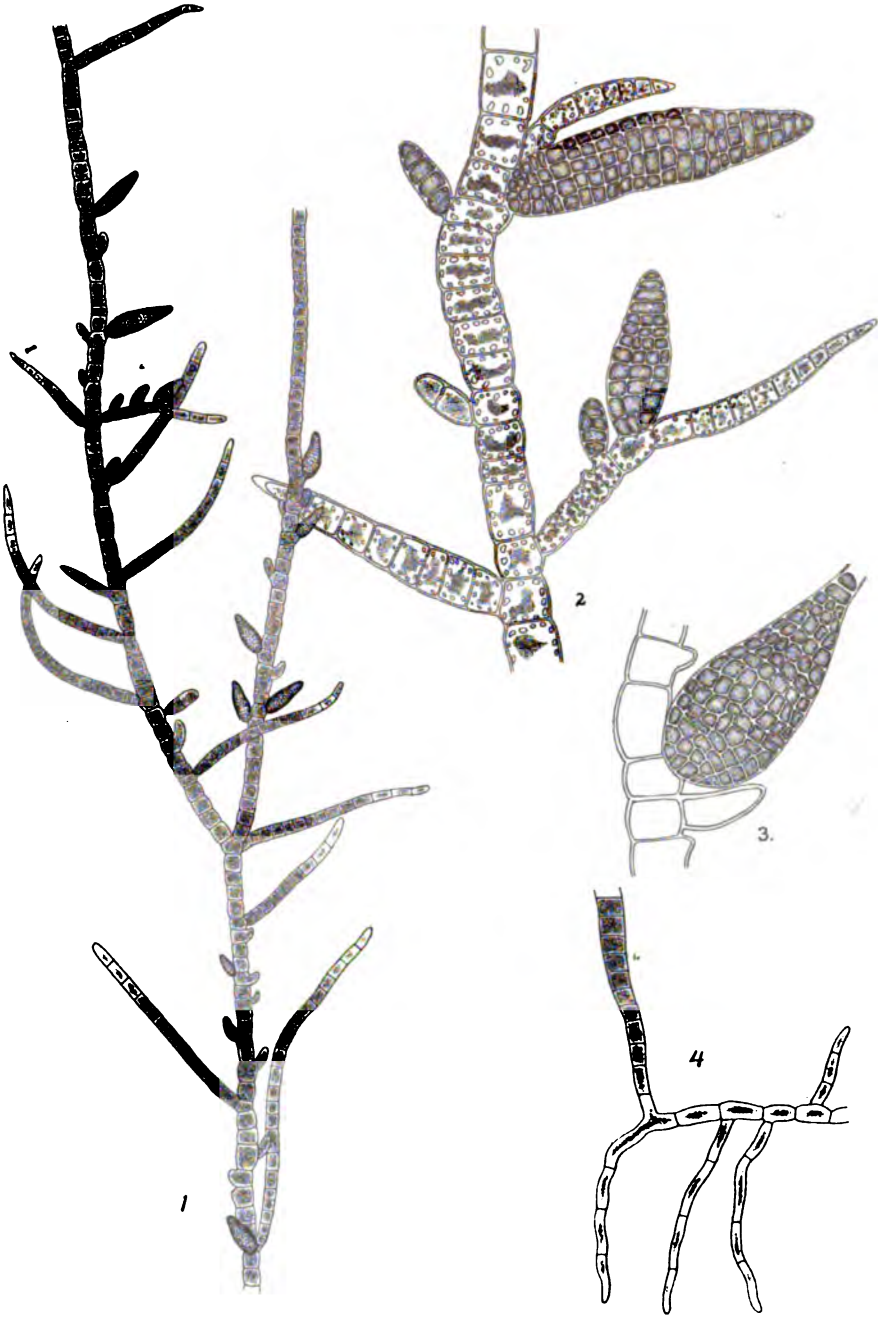
FIGS. 1 - 4. ECTOCARPUS HEMISPHAERICUS MINOR, FORM. NOV.
FIGS. 5 - 7. ECTOCARPUS PARASITICUS PACIFICUS, VAR. NOV.



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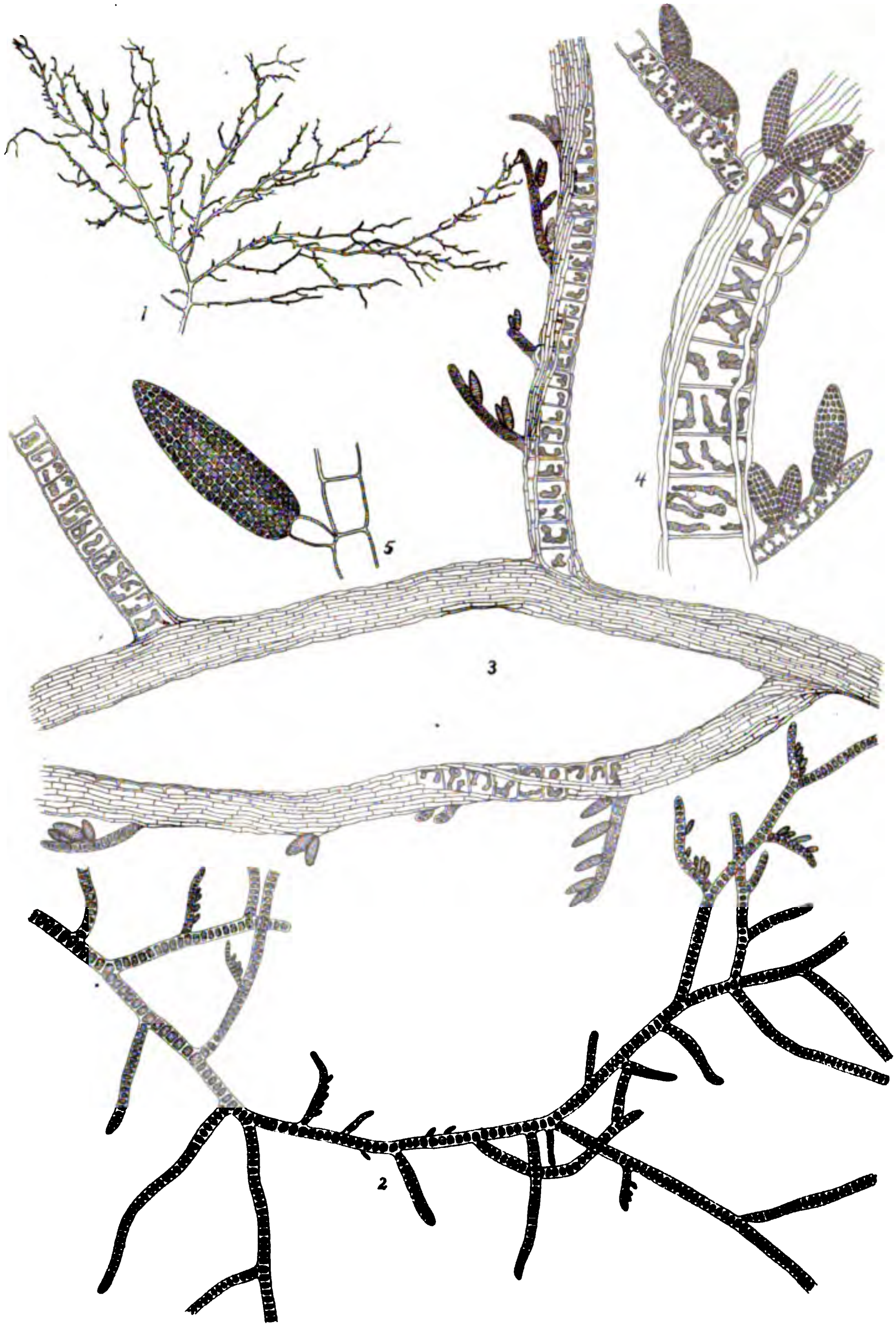
ECTOCARPUS MUCRONATUS, SP. NOV.



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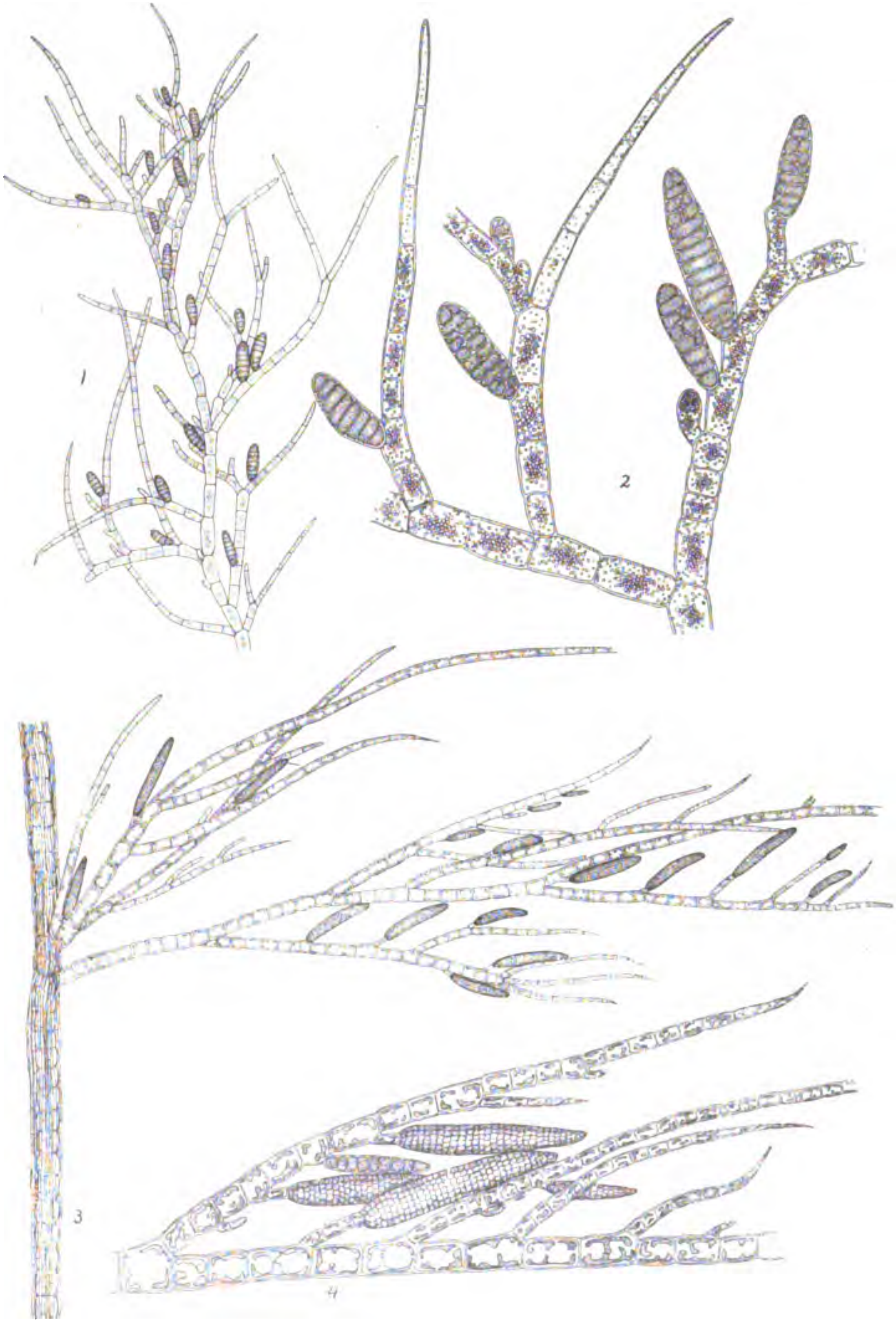
ECTOCARPUS CORTICULATUS, SP. NOV.



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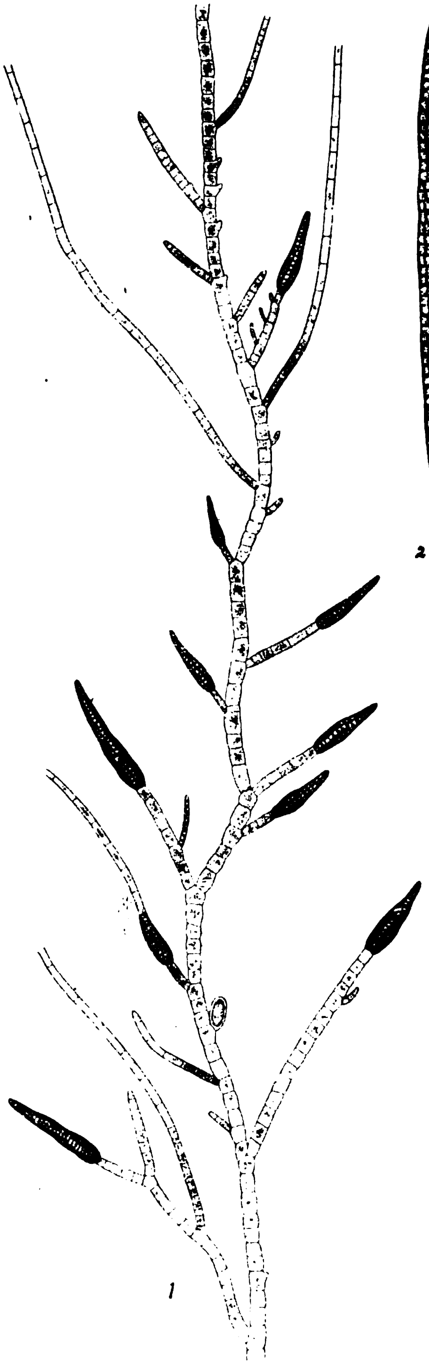
Figs. 1-2. Ectocarpus mitchellae Harv.
Figs. 3-4. Ectocarpus penicillatus Ag.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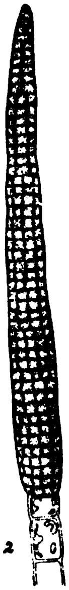
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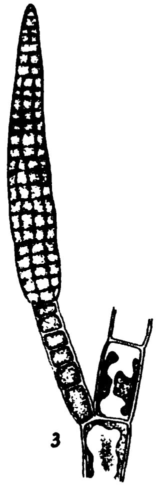
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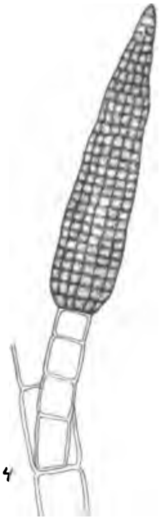
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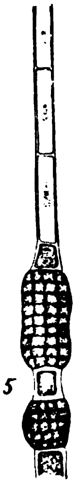
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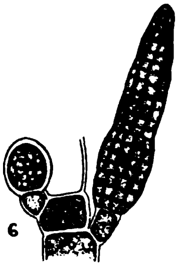
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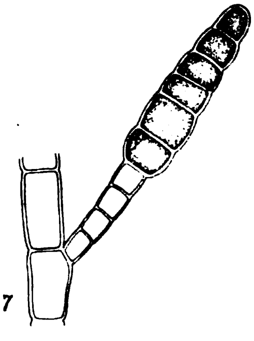
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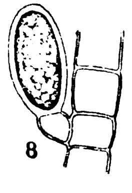
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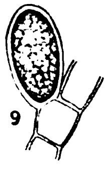
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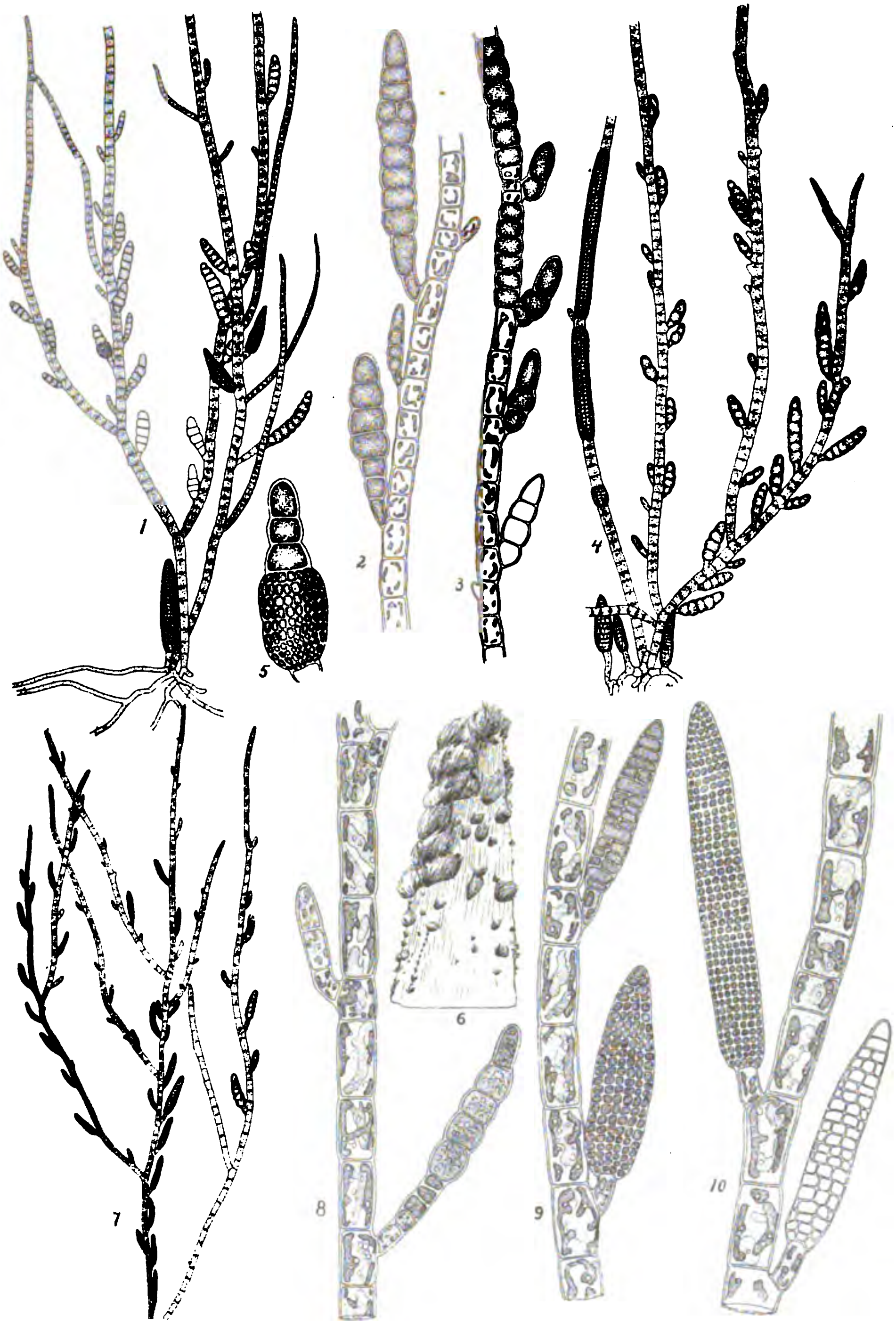

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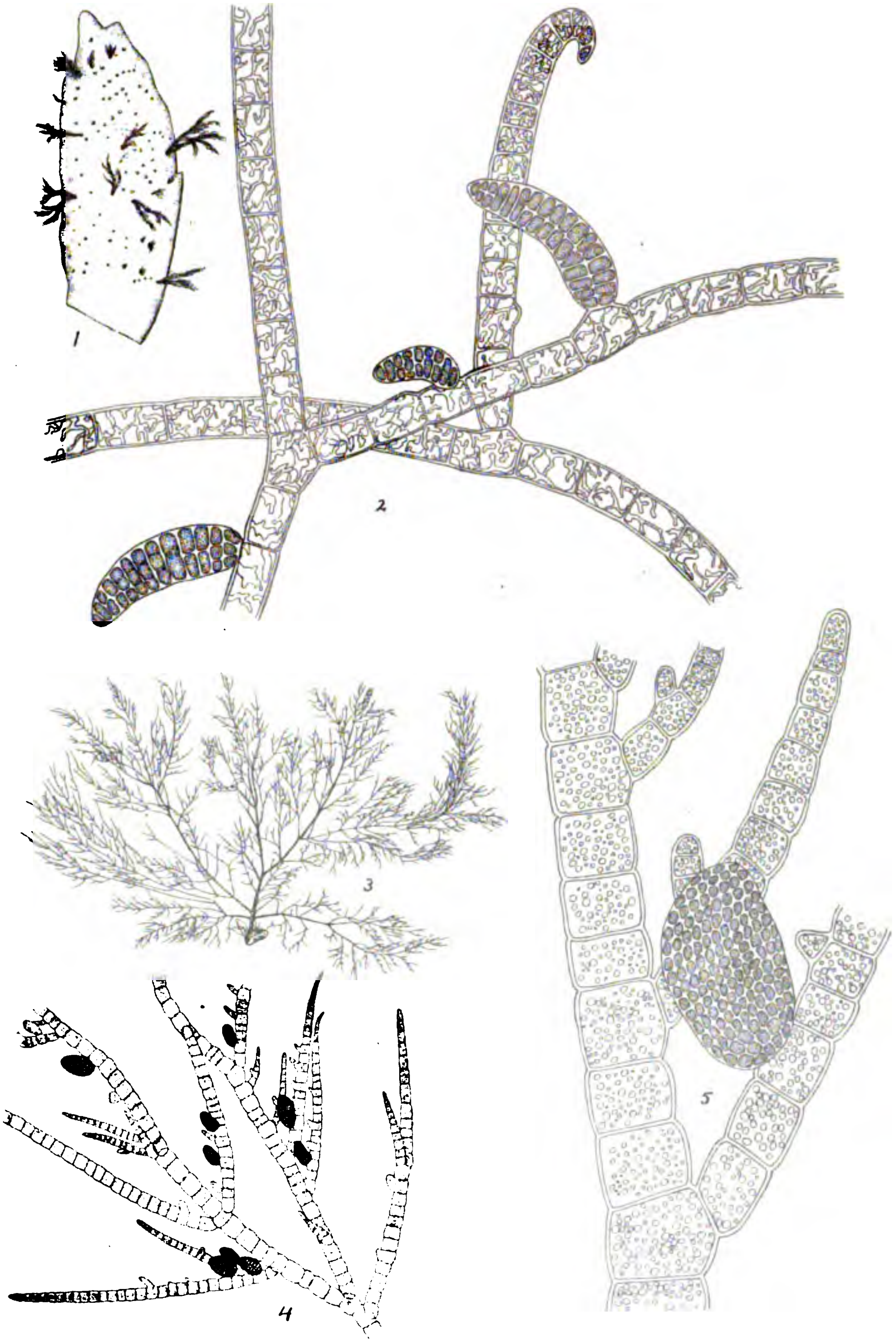
ECTOCARPUS CONFERVOIDES VARIABILIS FORM. NOV.



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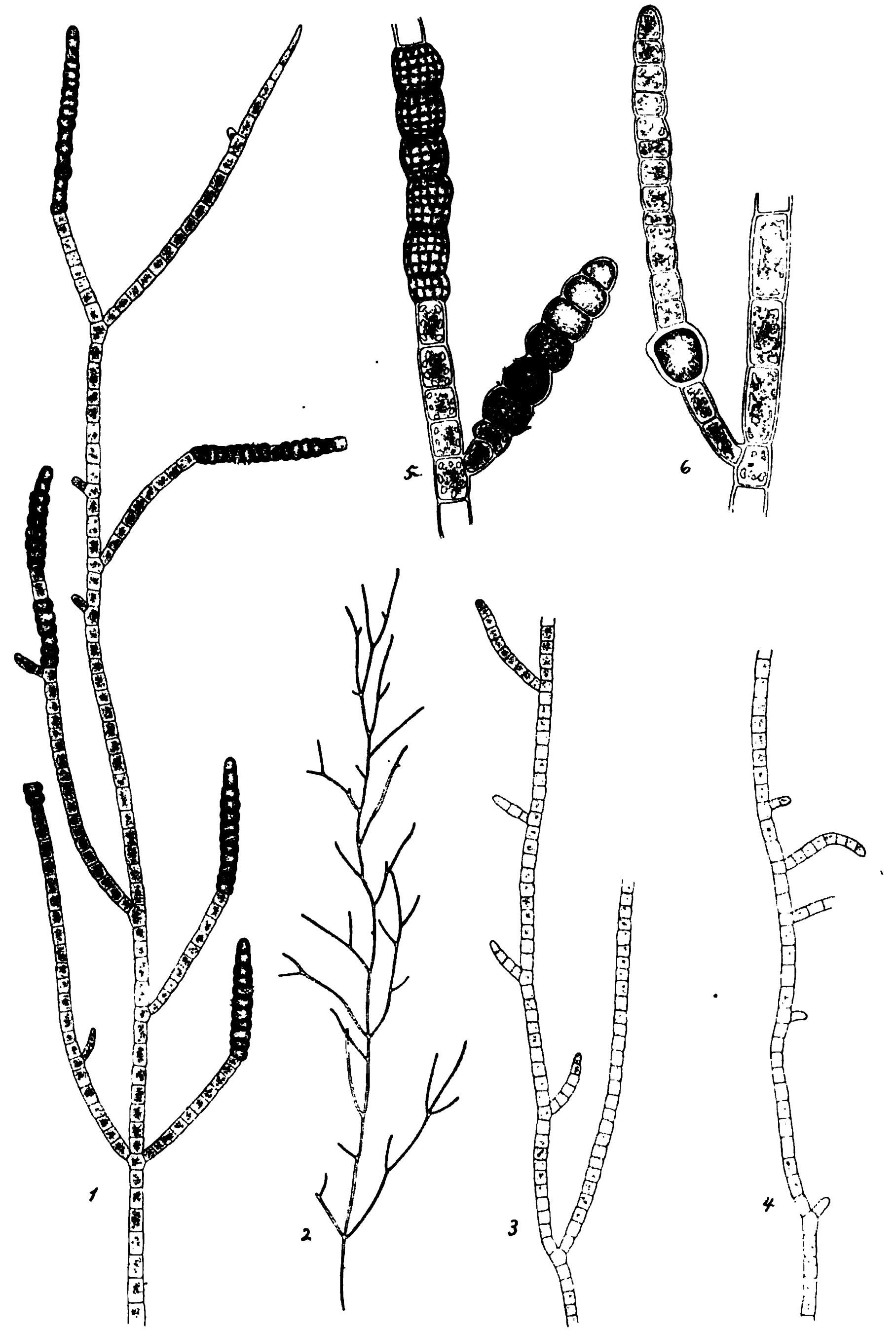
FIGS. 1 - 2. ECTOCARPUS TOMENTOSUS (HUDS.) LYNGB.
FIGS. 3 - 5. ECTOCARPUS GRANULOSUS (ENGL. BOT.) AG.



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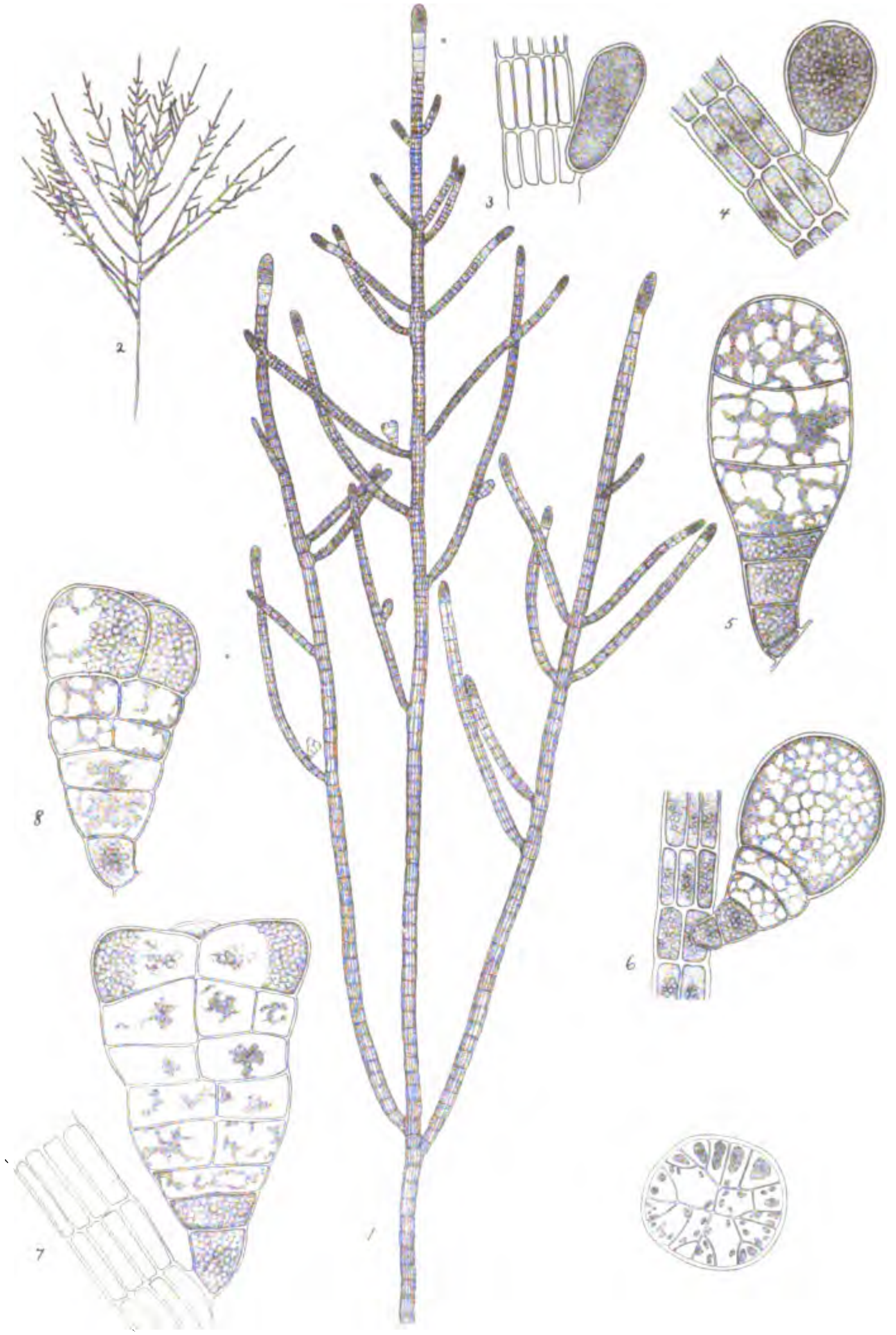
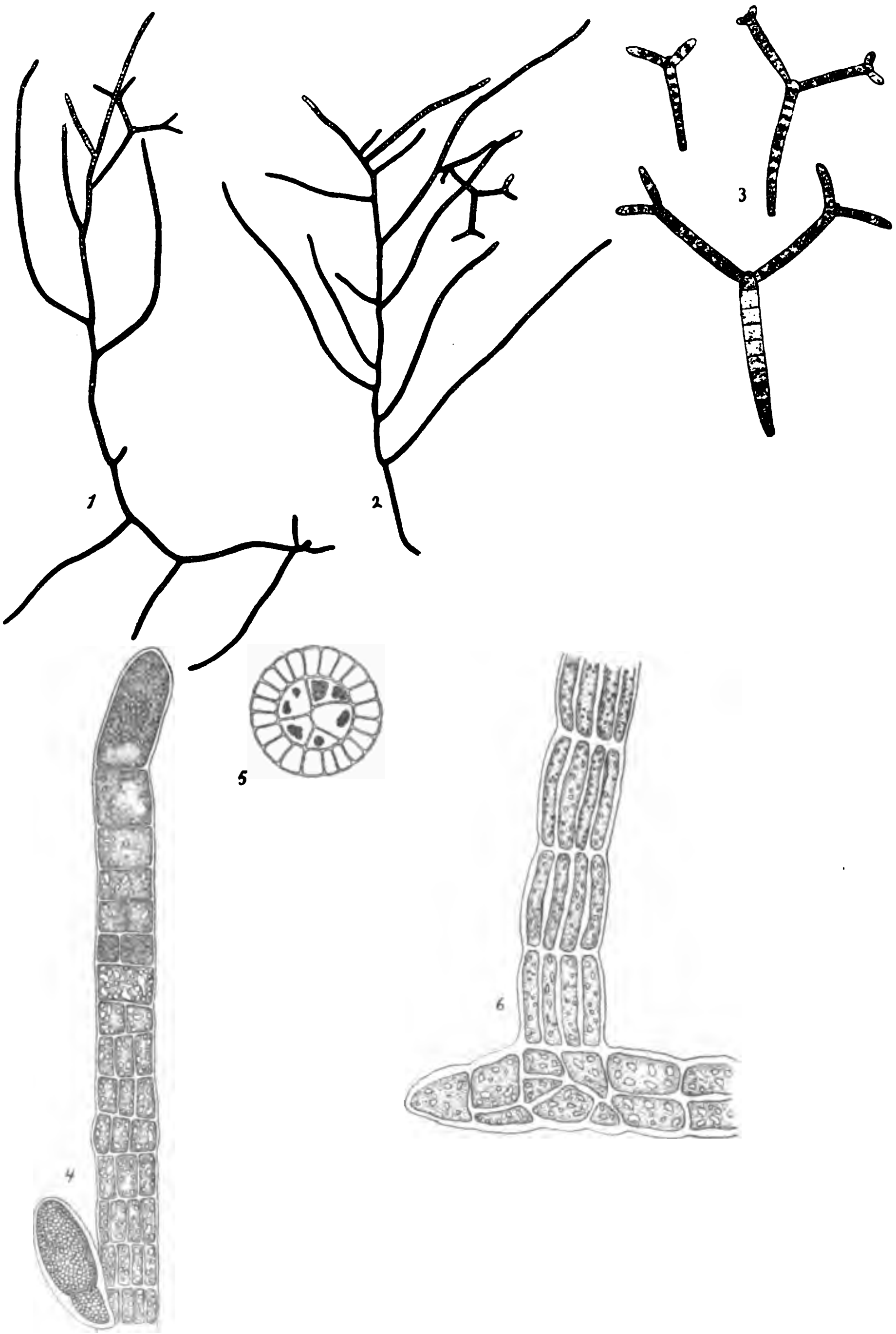
Figs. 1-2-5-6 Pylaiella littoralis densa, form. nov.
Figs. 3-4 Pylaiella littoralis, var.



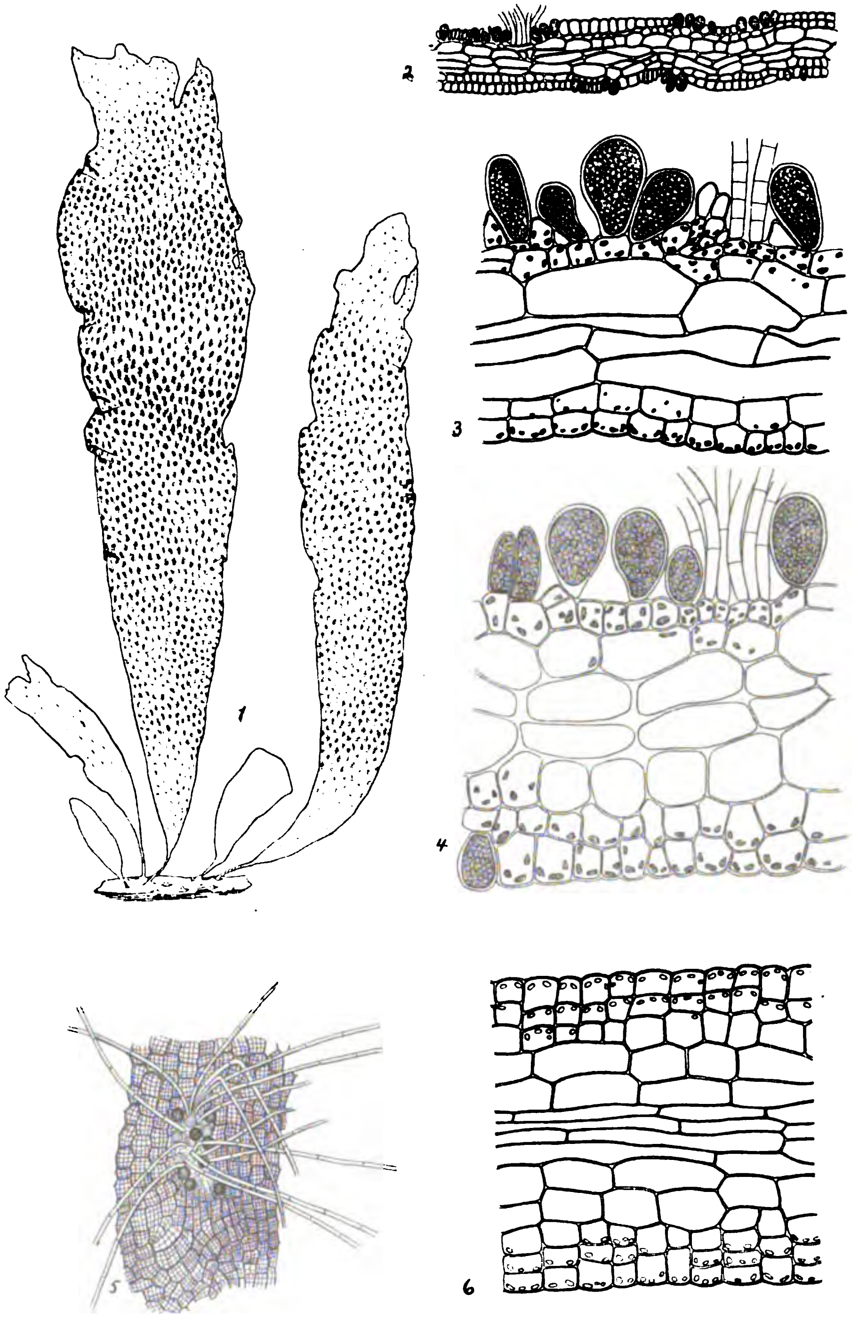
F. L. H. Del. [illegible]

SPHACELARIA TRIBULOIDES MENEGH.



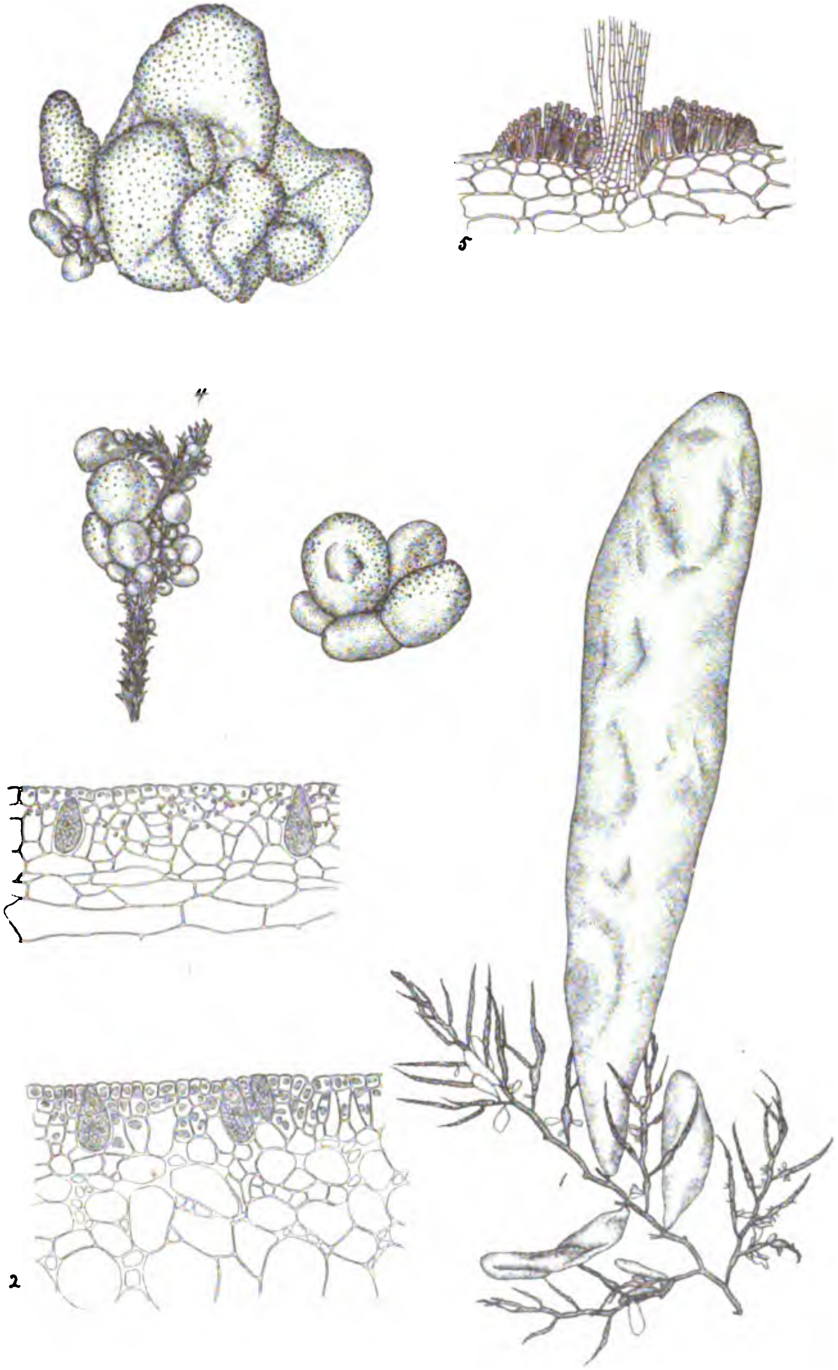
L.L.H. Fec. [illegible]

SPHACELARIA DIDICHOTOMA, SP. NOV.



BRITTON & REY S.F.

HALORHIPIS WINSTONII (ANDERS.) GEN. NOV.



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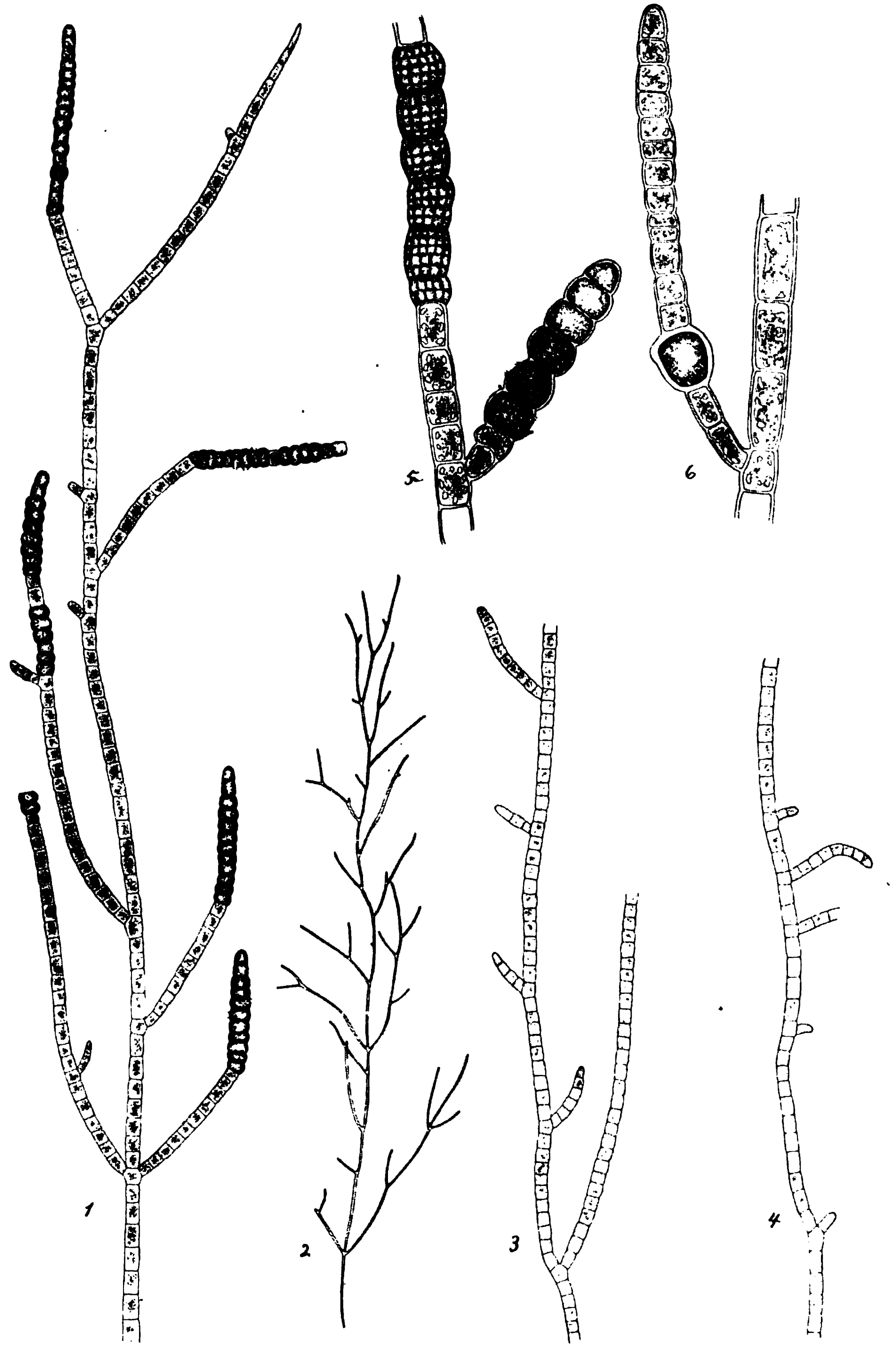
FIGS. 1-3. COILODESME CALIFORNICA *(RUPR.) KJELLM.*
FIGS. 4-5. SORANTHERA ULVOIDEA *POST. & RUPR.*



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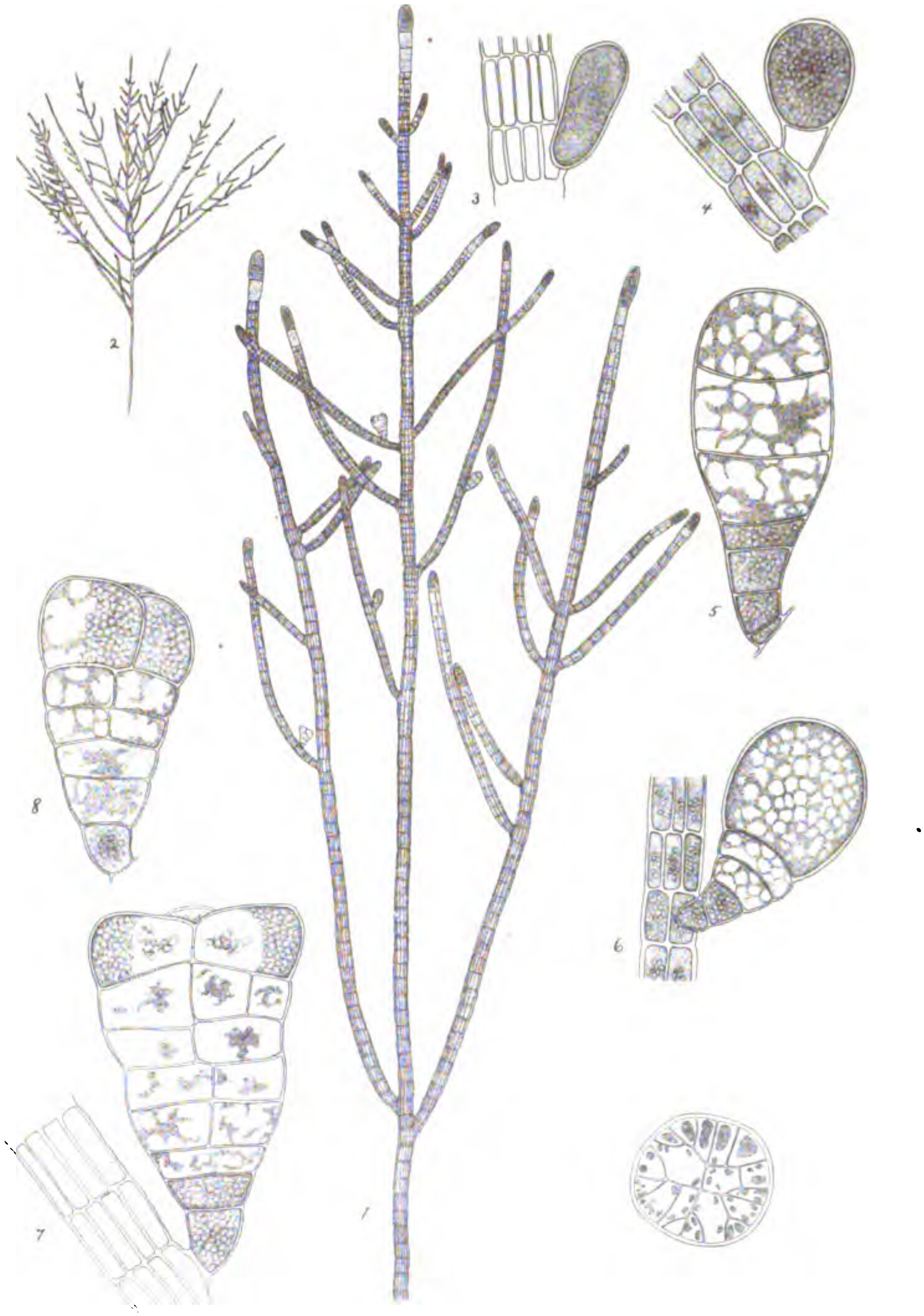
FIGS. 1-2-5-6. PYLAIELLA LITTORALIS DENSA, FORM. NOV.
FIGS. 3-4. PYLAIELLA LITTORALIS KJELL.



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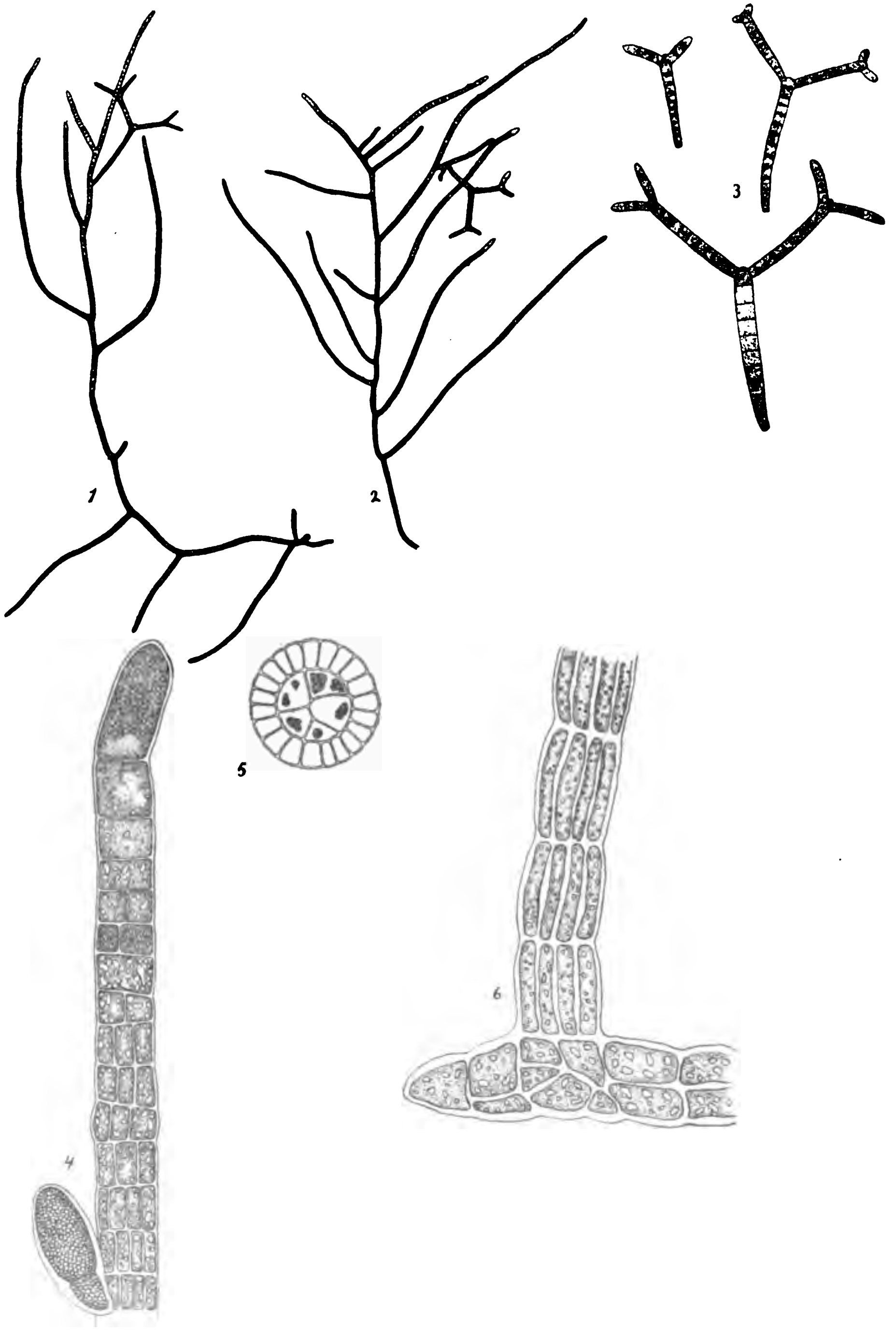
SPHACELARIA TRIBULOIDES MENEGH.



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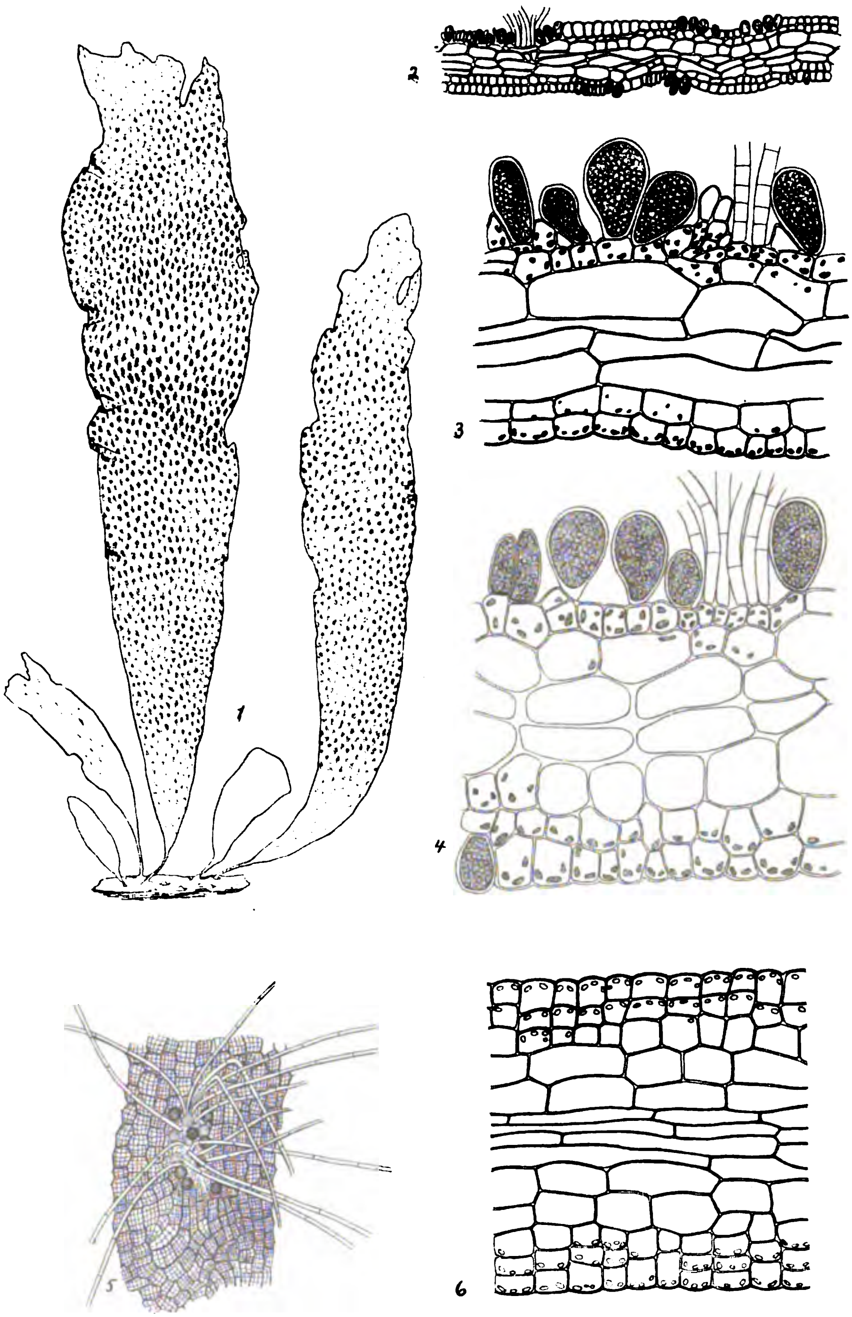
SPHACELARIA DIDICHOTOMA, SP. NOV.



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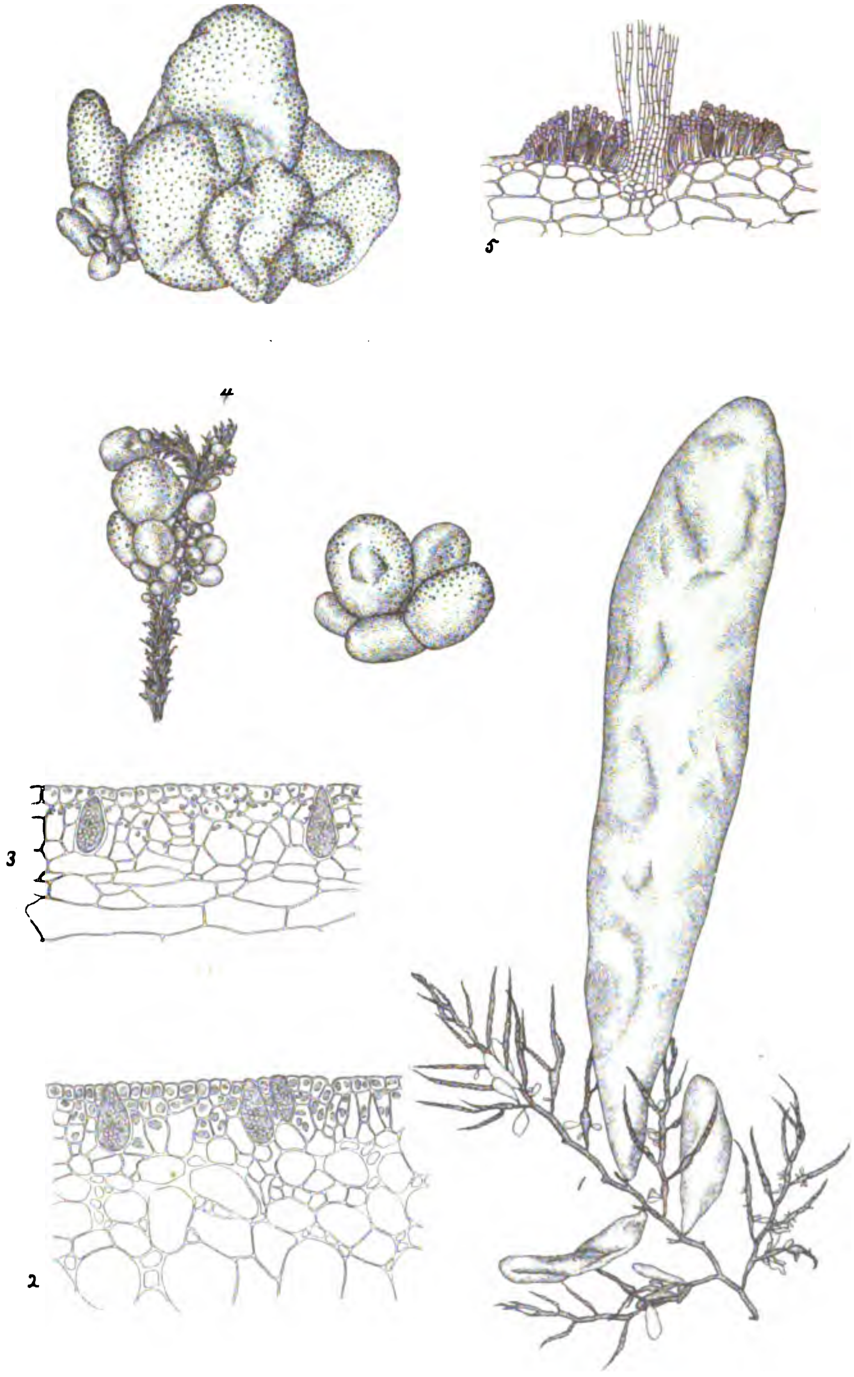
LITH. BRITTON & REY, S.F.

HALORHIPIS WINSTONII (ANDERS.) GEN. NOV.



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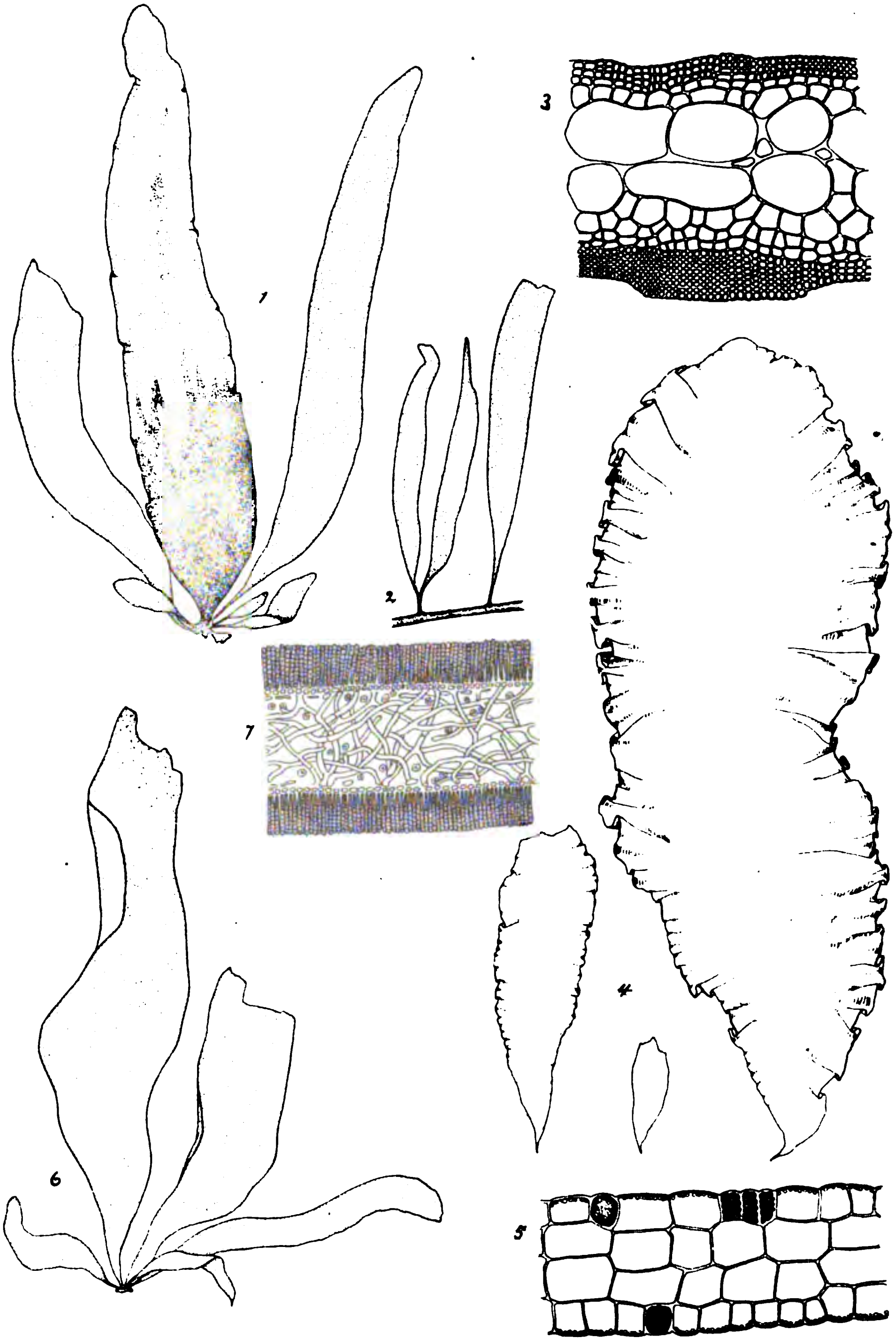
FIGS. 1 – 3. COILODESME CALIFORNICA [RUPR.] KJELLM.
FIGS. 4 – 5. SORANTHERA ULVOIDEA POST. & RUPR.



A.L.H. Del.

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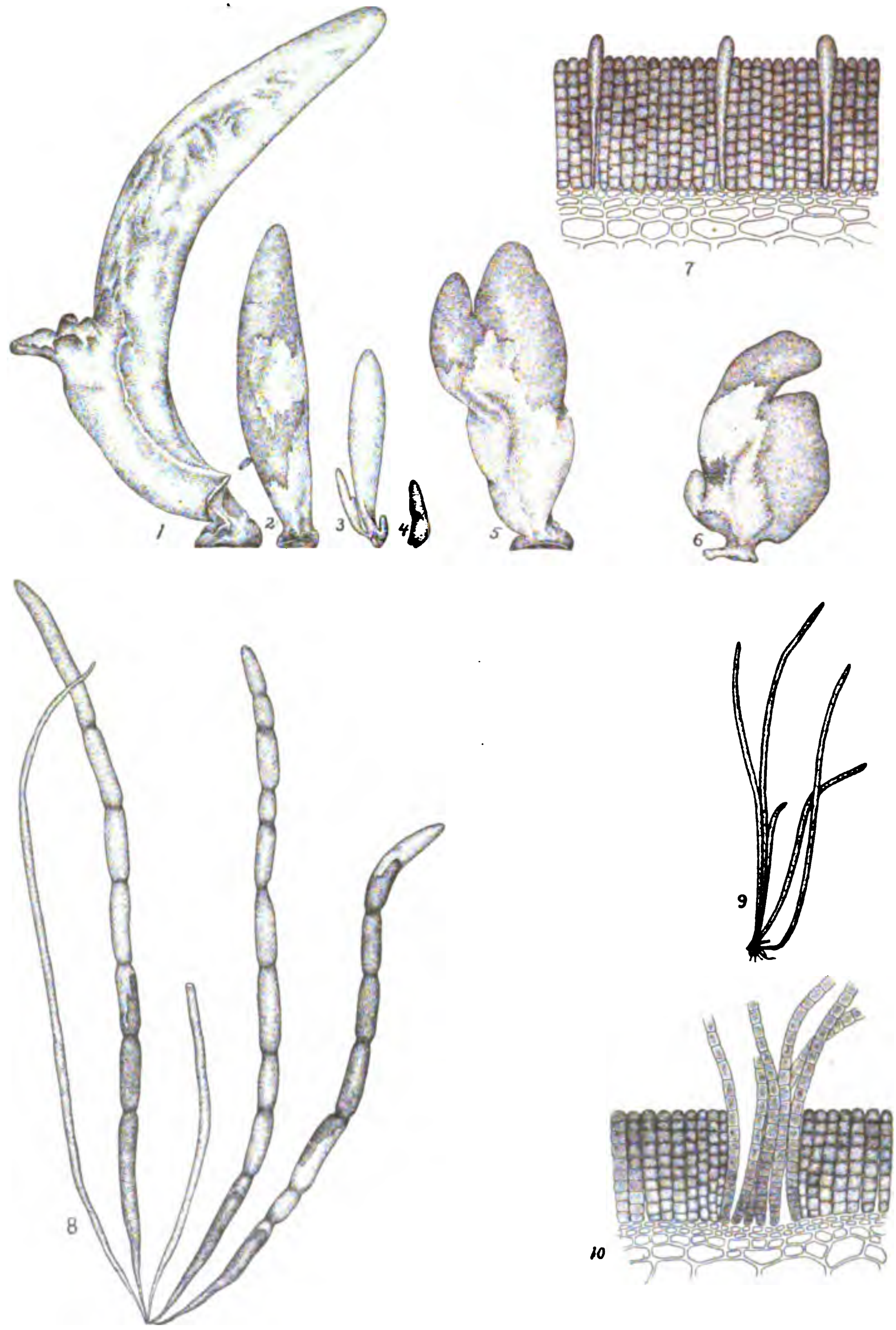
FIGS. 1 - 3. PHYLLITIS FASCIA (MUELL.) KUETZ.
FIGS. 4 - 5 HOMOEOSTROMA LATIFOLIUM J. AG.
FIGS. 6 - 7 ENDARACHNE BINGHAMIAE J. AG.



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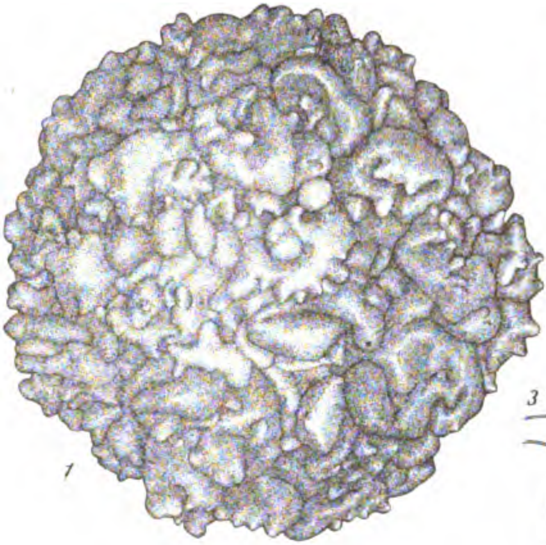
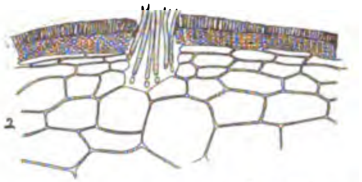
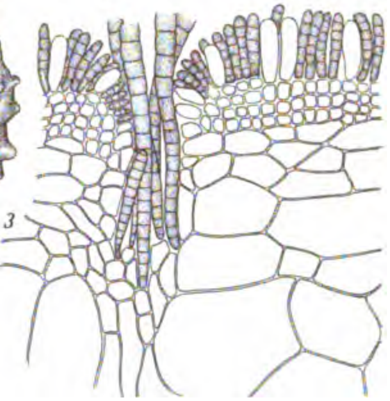
FIGS. 1 - 7. SCYTOSIPHON BULLOSUS, SP. NOV.
FIGS. 8 - 10. SCYTOSIPHON LOMENTARIUS *(LYNGB.) J. AG.*

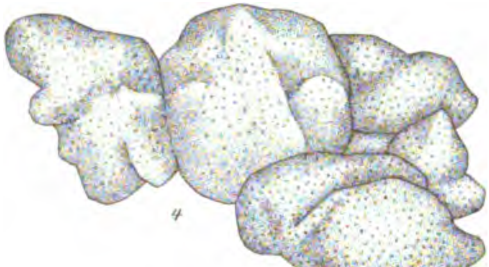
Proc. Cal. Acad. Sci. 3d Ser. Bot. Vol. I.

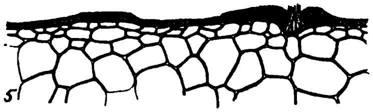
[Saunders] Plate XXXII

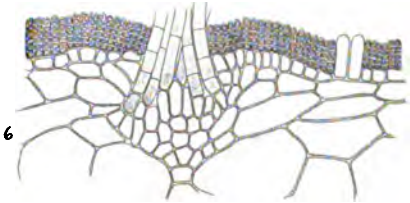


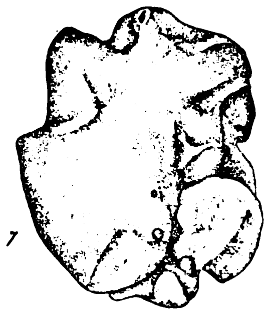


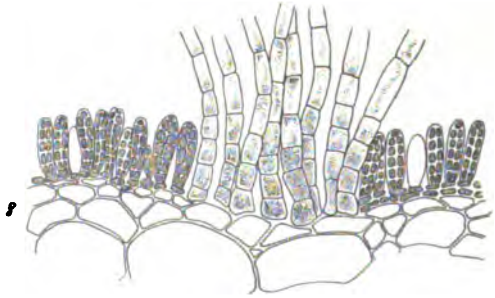












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Figs 1 - 3. Colpomenia tuberculata, sp. nov.
Figs 4 - 6. Colpomenia sinuosa expansa, form. nov.
Figs 7 - 8. Colpomenia sinuosa *(Roth) Derb & Sol.*

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*(Continued from Second Page of Cover.)*

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